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RESEARCH ARTICLE

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# Development of a *Delonix regia* decorticating machine

**S. J. Ojolo** | **J. I. Orisaleye** | **A. A. Ogundare** | **D. Kadiri**

Department of Mechanical Engineering, University of Lagos, Akoka, Nigeria

**Correspondence**
J. I. Orisaleye, Department of Mechanical Engineering, University of Lagos, Akoka 100213, Nigeria.
Email: ifeorisaleye@gmail.com

*Delonix regia* has good potential for medicinal, nutritional, and energy applications. However, the manual process of decorticating *Delonix regia* is labor-intensive, slow, and tedious. Mechanization of the decorticating process would be of value to its utilization for medicinal, food, feed, or fuel purposes. In this study, preliminary compressive strength tests were carried out on the *D. regia* pods to determine the force required to fracture the pods. Subsequently, a machine capable of separating the *D. regia* seeds from the pods was designed based on impact of beaters on pods. A prototype of the developed machine was evaluated to determine its performance in terms of decorticating efficiency, whole seed recovery, feed rate, and throughput. The compressive tests showed that a force of 602 N was required to fracture the *D. regia* pods in transverse orientation. The decorticating efficiency of the designed machine, which had a power rating of 6 kW, was 100.0%, and the whole seed recovery was estimated to be 98.4%. The throughput of the machine was 56.4 kg/h. The developed decorticating machine allows enhanced potential for medicinal and nutritional application of *D. regia*.

**KEYWORDS**
decorticating, *Delonix regia*, efficiency, machine design, pod, seed

## 1 | INTRODUCTION

*Delonix regia* is a many-branched spreading flat-crowned tree that is well known for its brilliant display of red-orange bloom. Suhane et al[1] claimed that the tree is native to Madagascar and Zambia and exotic in Brazil, Burkina Faso, Cyprus, Ethiopia, India, Jamaica, Nigeria, Puerto Rico, Singapore, South Africa, Uganda, United States of America, Egypt, Eritrea, Kenya, Mexico, Niger, Sri Lanka, Sudan, and Tanzania. *D. regia* is also known in English as Flamboyant, Flame tree, Flame of the forest, Gold mohar, Julu tree, Peacock flower, and Royal Poinciana.[2] In Nigeria, it is known as *Sekeseke* in Yoruba language. *D. regia* is widespread in most tropical areas of the world.

Flame tree is an ornamental plant that reaches a height of 10 to 15 m with woody stems. It is ranked among the top five most beautiful tropical trees in the world and produces, in spring, striking flame-like scarlet and yellow flowers. The fruit is leguminous, stipitate, unilocular, elongate, and oblong, which is green when young but turns hard, dark brown, and woody when mature.[1] The length of the fruit is between 30 and 75 cm, its thickness is about 3.8 cm, and its width is between 5 and 7.6 cm. The seeds of *D. regia* are hard, woody, glossy, oblong, and olive brown or black in color. The seeds are about 2 cm long.[3] Figure 1 shows a picture of *D. regia* pods and seeds.

**FIGURE 1** *Delonix regia* pods and seeds

*D. regia* has large range of medicinal applications for antimicrobial and antifungal activities and antioxidants, and its seeds contain flavonoids used as domestic wound healing agent.[4-6] The seeds are also used occasionally as beads.[7] Abulude and Adejayan[8] investigated the nutritional value of *D. regia* and advised that despite the presence of bioactive substances, the seeds should be properly processed due to antinutrients. *D. regia* is rich in protein and can serve as a substitute for groundnut cake in poultry feed.[8,9] Gums extracted from *D. regia* seed makes it potentially resourceful in the food industry.[10]

Seed oil extracted from *D. regia* has potential for control of maize weevils. This facilitates traditional grain storage practices if incorporated in grain storage system.[11] The extracted seed oil also has the potential for green production of biodiesel.[12,13] Olagbende et al[14] also utilized pods of *D. regia* in generating alternative fuels through pyrolysis.

In Nigeria, all parts of *D. regia* have not been extensively exploited for food or feed and consequently mostly regarded as waste.[8] Traditional extraction of the seed from the pod is done manually. Matured pods are collected by pruning poles and any unopened pods are usually dried for 1 month when the sun is at its peak. These are then opened with much effort to remove the seeds that are loosely attached in lateral grooves. The pods are hard, which makes it difficult to open. After the pods are dried under the sun to ensure that there is little or no water present, it is opened with the use of knife from the side, which is the path of least resistance. Separation of the seeds is then carried out by hand picking. Another practice is to soak the pods in water for a night, after which the pods are twisted to open. The manual method of separating seeds from the pods is usually a labor-intensive, slow, and tedious process. There is, therefore, a need to develop mechanized means of separating the seeds from the pods.

Shelling, which is the removal of shells or dry pods, has an objective of producing clean whole seeds free of cracks.[15] Several machines working on different principles have been developed for separating different nuts and seeds from their shells and pods. Gong et al[16] reviewed cashew nut shelling techniques. Ojolo et al[17] developed a variable size nut cracker which had cracking efficiency of 87%. Ojolo et al[18] developed a cashew nut shelling machine working on the principle of impact. Ojolo et al[19] and Ojolo and Ogunsina[20] carried out studies on a cashew nut cracking device. Lim et al[21] evaluated the performance of a jatropha fruit shelling machine and obtained a separation efficiency of 91.25%. Kheiralla et al[22] also developed a jatropha seed shelling machine with a shelling percentage of 46.33%. Fadele and Aremu[23] developed a machine for shelling *Moringa oleifera*.

Pius et al[24] developed and evaluated a castor seed shelling machine. Rajput et al[25,26] developed a green chickpea pod stripping and shelling machine. A table mounted device for cracking Dika nut was developed by Ogunsina et al.[27] Oluwole et al[28] developed a sheanut cracker which operates on the principle of impact. Omobuwajo et al[29] and Nwigbo et al[30] designed machines to shell and dehull for African breadfruit.

Oriaku et al[31] identified methods of melon dehusking as impact and attrition and carried out a comparative analysis of both methods. Adedoyin et al[32] developed a melon shelling machine with 62.5% shelled whole melon seeds. Other melon seeds shelling machine have been developed by Adekunle et al,[33] James et al,[34] Shittu and Ndrika,[35] and Sobowale et al.[36]

Oluwole et al[37] evaluated centrifugal impaction devices for shelling bambara groundnut and obtained a shelling efficiency of 96%. Mangave and Deshmukh[38] presented the design of a portable groundnut shelling machine. Mohammed and Hassan,[39] Raghtate and Handa,[40] and Ugwuoke et al[41] also presented designs of groundnut shelling machines. There has been no report of an automated method for the separation of *Delonix regia* seed from the pod. The primary objective of this work is, therefore, to design and develop a motorized *Delonix regia* pod decorticating machine and evaluate its performance.

| Experiment no. | Compressive stress at break, MPa | Compressive strain at break | Compressive load at break, N | Deformation, mm |
|---|---|---|---|---|
| 1 | 0.331 | 0.136 | 410.9 | 5.2 |
| 2 | 0.362 | 0.176 | 448.3 | 6.8 |
| 3 | 1.095 | 0.162 | 1357.8 | 6.0 |
| 4 | 0.155 | 0.110 | 191.8 | 4.4 |
| Mean | 0.486 | 0.146 | 602.2 | 5.6 |
| Standard deviation | 0.416 | 0.029 | 516.3 | 1.0 |

**TABLE 1** Results of the compression test carried out on the pod in the transverse orientation

| Experiment no. | Compressive stress at break, MPa | Compressive strain at break | Compressive load at break, N | Deformation, mm |
|---|---|---|---|---|
| 1 | 0.024 | 0.050 | 9.0 | 4.8 |
| 2 | 0.006 | 0.091 | 2.3 | 9.0 |
| 3 | 0.125 | 0.092 | 46.9 | 10.3 |
| 4 | 0.058 | 0.442 | 21.6 | 66.8 |
| Mean | 0.053 | 0.169 | 20.0 | 22.7 |
| Standard deviation | 0.052 | 0.183 | 19.7 | 29.5 |

**TABLE 2** Results of the compression test carried out on the pod in the longitudinal orientation

## 2 | PRELIMINARY EXPERIMENTS

The force required to fracture the pods under static load was determined by compressive test using a universal load testing machine (Instron Electromechanical Testing Systems, Model 3369) at the Material Testing Laboratory of the Centre for Energy Research and Development, Obafemi Awolowo University, Ife, Nigeria. The tests determined the forces required to effectively fracture the pod when in the longitudinal and transverse orientations. Eight specimens of dry *Delonix regia* pods were used. The findings are presented in Tables 1 and 2. The average force required to break one pod is 602 N in the transverse orientation. The average force required to fracture the pods in longitudinal orientation is 20 N. The maximum force required to fracture the pod is 1360 N. For the design of the machine to separate the seeds of *Delonix regia* from the pods, the average force is used.

## 3 | DESIGN ANALYSIS

### 3.1 | Description and operating principle of machine

The pods are fed into the machine through a hopper which directs the pods into the crushing unit. The crushing unit has a shaft carrying beaters that are mounted on a shaft. The beaters are enclosed in a cylindrical container that has fixed jaws on its sides, which serves as counter beaters to make the crushing process effective. A mesh is placed beneath the unit to ensure that the crushing process is effective. The beaters are powered by an electric motor that is connected to the shaft by pulleys.

During operation, the beaters hurl *Delonix regia* pods toward the fixed jaws or counter beaters. This cracks the pods due to the impact of the beaters on the pods against the fixed jaws. The crushed pods and seeds pass through the mesh after the size has been sufficiently reduced. The crushed mix of chaff and seed then fall into the separation compartment. Separation is carried out by the use of a blower, which is able to remove light chaff particles that have low densities relative to the seed. Sieving and vibration is also utilized to separate the seeds from larger chaff particles.

### 3.2 | Design analysis

#### 3.2.1 | The crushing unit

The beaters impact on the pods against the fixed jaws to fracture the pods. The cylindrical container housing the crushing unit has a diameter of 200 mm. The tip diameter of the beaters is selected to be 190 mm to give a clearance of 5 mm from the barrel. Assuming that the impact force is applied at the tip, the torque, $T$, required to crack the pods, is estimated from

$$T = F \times \frac{d}{2}. \quad (1)$$

$F$ is the force required to fracture the pods and $d$ is the tip diameter of the beaters. The minimum torque on one beater for cracking one pod is estimated to be 57.2 Nm. The shaft carries the beaters in the crushing unit. There are 26 beaters on the shaft arranged in two rows.

According to Kabir and Fedele,[42] the operating speed for seed or nut shelling or decortications ranges from 63 to 4570 rpm depending on the shelling device. It was stated that it is usually high, in most cases, for centrifugal impaction devices. Taking the speed from within the range as 600 rpm, the power requirement, $PW_c$, for crushing the pods, is estimated from[43,44]

$$PW_C = \frac{2\pi NT}{60}. \quad (2)$$

The required torque, $T$, has been determined to be 57.2 Nm. The power required for crushing the pods is, therefore, 3.6 kW.

### 3.2.2 | Blower

The blower is an axial fan that removes small particulate chaff of the crushed chaff of the pods. The force of the air delivered by the fan must be greater than the weight of the chaff. Comparing bulk densities similar materials as the *Delonix regia* chaff with paper,[45] the average mass of the chaff per unit area, $m$, may be taken as 250 g/m$^2$. For the cross-sectional area, $A$, of fan taken as 200 mm, the maximum weight of material to be removed is

$$W = (mA)\, g. \quad (3)$$

Taking acceleration due to gravity, $g$, as 9.8 m/s, the weight of the chaff is 61.6 N. From the momentum equation, assuming an initial velocity of zero in the direction of flow, the force of flow is estimated from Bird and Ross[46]

$$F = \dot{m}v = \rho_a A v.v = \rho_a A v^2. \quad (4)$$

$v$ is the required velocity of the air stream, $\rho_a$ is the density of air assumed to be 1.225 kg/m$^3$, and $F$ is assumed equal to the weight, $W$, of the lightweight material. To evaluate the minimum required velocity of air flow, $v$,

$$v = \left[\frac{W}{\rho_a A}\right]^{1/2}. \quad (5)$$

The velocity of air flow is estimated as 40 m/s. The volumetric flow rate, $Q$, is estimated from

$$Q = Av. \quad (6)$$

The volumetric flow rate is estimated to be 1.25 m$^3$/s. The pressure produced by the impeller of the fan is[47]

$$P = \frac{1}{2}\psi \rho_a v^2. \quad (7)$$

$\psi$ is the pressure coefficient, which is taken as unity. The air pressure is, therefore, 980 N/m$^2$. The power, $PW_f$, required by the fan is estimated from[47]

$$PW_f = \zeta PQ. \quad (8)$$

$\zeta$ is a coefficient flow recirculation and impeller exit losses taken as 1.2. The power required for the fan is determined to be 1.47 kW.

### 3.2.3 | Design of shaft for beaters

The forces on the shaft are shown in Figure 2. It is assumed that the force of impact on the impellers, $F$, is the crushing force. The force, $F_{belt}$, is due to the tension of the belt on the pulleys to produce the required torque of 57.2 Nm.

To determine $F_{belt}$, the size of the pulley driving the shaft, $D_2$, is determined from[43,44]

$$D_2 = \frac{N_1}{N_2}(D_1). \tag{9}$$

The size of the pulley on the prime mover, $D_1$, is taken as 100 mm; the speed on the prime mover, $N_1$, is 1200 rpm; the required speed of the beaters, $N_2$, is 600 rpm. The required diameter of the pulley to operate the shaft carrying the beaters is 200 mm.

The torque, $T$, delivered by the pulley to the shaft, is expressed as[43,44]

$$T = (T_1 - T_2)\frac{D_2}{2}. \tag{10}$$

However, the relationship between tension on the tight side of the belt, $T_1$, and the slack side of the belt, $T_2$, is[43,44]

$$T_1 = T_2 e^{\mu\theta}. \tag{11}$$

The friction coefficient, $\mu$, is taken as 0.3, and the angle of wrap, $\theta$, is determined from[43,44]

$$\theta = 180 + 2\sin^{-1}\left(\frac{D_1 - D_2}{2C}\right). \tag{12}$$

The center distance, $C$, of the pulley is assumed to be 600 mm. The angle of wrap is, therefore, 189.6° (3.3 *rad*). The tension forces in the tight and slack sides of the belt of the pulley are then estimated to be 910.2 N and 338.2 N. The force, $F_{belt}$, is the sum of the tension forces resolved to the respective axis obtained to be 1244.0 N and 48.9 N in the vertical and horizontal directions, respectively. The bending moment diagram, in Figure 3, shows that the maximum bending moment is 988.0 Nm.

Using the Tresca's yield criterion, the equivalent twisting moment, $T_e$, of the combination for loads is[43,44]

$$T_e = \sqrt{(k_m M)^2 + (k_t T)^2}. \tag{13}$$

The maximum bending moment on the shaft, $M$, is 988.0 Nm; the twisting moment, $T$, is 57.2 Nm; the combined shock and fatigue factor for bending, $k_m$, is taken as 1.5; the combined shock and fatigue factor for shear, $k_t$, is taken as 1.0. The

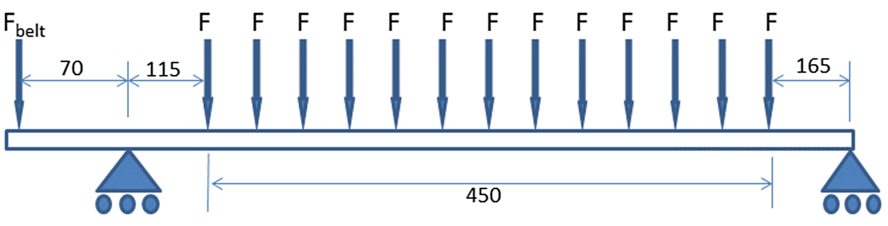


**FIGURE 2** Forces on the shaft carrying the beaters (dimensions in mm)

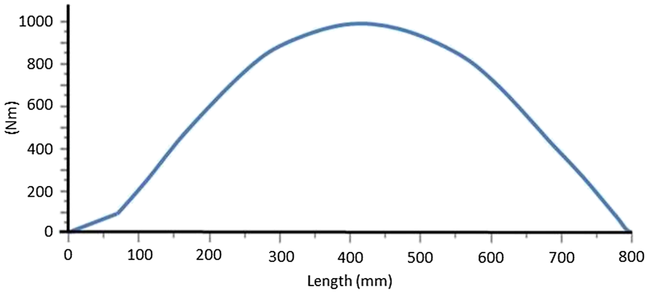


**FIGURE 3** Resultant bending moment diagram of shaft carrying beaters

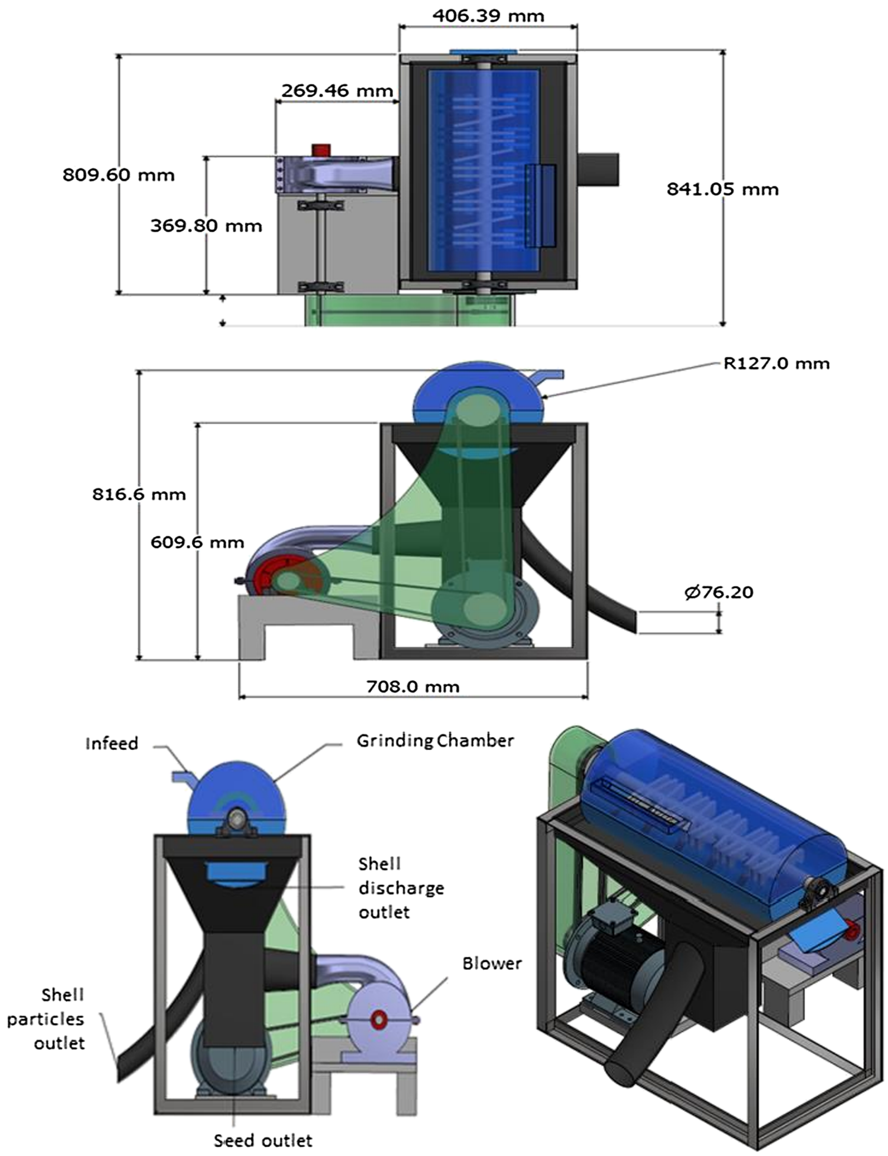


**FIGURE 4** The *Delonix regia* seed separator machine

equivalent twisting moment is estimated to be 1483.1 Nm. The shaft diameter is estimated from[43,44]

$$d = \left(\frac{16T_e}{\pi\tau}\right)^{\frac{1}{3}}. \tag{14}$$

Assuming the material for the shaft to be mild steel with a yield strength of 600 MPa, the design shear stress, taken as 0.3 times the yield strength, is 180 MPa. The shaft diameter is, therefore, estimated to be 34.8 mm. A standard shaft diameter of 35 mm is selected.

The drawing of the machine is shown in Figure 4.

### 3.2.4 | Power rating of electric motor

The electric motor is required to power the crushing unit and the blower. The power required in the crushing unit has been estimated to be 3.6 kW, while the blower requires 1.47 kW. The total power requirement of the machine is 5.07 kW. An electric motor with a power rated at 6 kW or 8 hp is selected.

## 3.3 | Performance evaluation of the machine

To investigate the performance of the machine, the *Delonix regia* pods were fed into the machine through the hopper while the machine was in operation. The separated seeds were collected, and the quantity of seeds, cracked whole seeds, uncracked seeds, and broken seeds were determined. The cracking or decorticating efficiency (DE) was determined from

$$\mathrm{DE} = \frac{\text{Total number of completely cracked pods}}{\text{Total number of fed pods}} \times 100\%. \tag{15}$$

The whole seed recovery (WSR) was determined from:

$$\mathrm{WSR} = \frac{\text{whole seeds recovered}}{\text{Total number of seeds in the pods}} \times 100\%. \tag{16}$$

The feed rate evaluated as

$$\text{feed rate} = \frac{\text{completely shelled pods}}{\text{shelling time}}. \tag{17}$$

The throughput was estimated from

$$\text{Throughput}\ \left(\text{kg}/h\right) = \text{mass} \times \text{shelling rate}. \tag{18}$$

Seed breakage ratio (SBR) was determined from Ndukwu and Asoegwu[48]

$$\mathrm{SBR} = \frac{C_D}{C_D + C_U} \times 100\%, \tag{19}$$

where $C_d$ = cracked and damaged pods and $C_u$ = cracked and undamaged pods.

## 4 | RESULTS AND DISCUSSION

The developed machine for decorticating of the *D. regia* pods was evaluated to determine its performance. The number of cracked and uncracked pods (CP and UP, respectively) were determined along with number of cracked whole seeds (CW) and broken seeds (BS). Moreover, the DE, SBR, and WSR were determined during evaluation. The results obtained for the identified performance metrics during decorticating are presented in Tables 3 and 4. Table 3 shows the results when one pod was fed into the machine. Table 4 shows the results of feeding five pods into the machine over a period of 30 seconds. It is seen that the number of *D. regia* seeds in the pods ranges between 37 and 41.

The decorticating efficiency was evaluated on the basis of the number of completely shelled pods. The *Delonix regia* seed separating machine shelled all pods, which resulted in decorticating efficiency of 100.0%. The same results for decorticating efficiency were obtained for single pods and multiple pods. Oluwole et al[28] also obtained efficiency of 100.0% for a sheanut cracker. Subramanian et al[49] obtained shelling efficiency of 76.7% for sunflower seeds dehuller, and Romuli et al[50] obtained maximum efficiency of 84.6%. Jain and Kumar[51] found that increasing speed improved shelling efficiency of a cashew nut shelling machine, but contrary observation was made by Balami et al[52] for a castor seed shelling machine. Romuli et al[50] and Subramanian et al[49] also found that increasing seed sizes improved the shelling efficiency of machines for jatropha and sunflower, respectively.

**TABLE 3** Results of performance of machine for processing of 1 pod

| S/N | NS | CP | UP | CW | BS | DE (%) | SBR (%) | WSR (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 37 | 1 | 0 | 36 | 1 | 100 | 2.7 | 97.3 |
| 2 | 41 | 1 | 0 | 40 | 1 | 100 | 2.4 | 97.6 |
| 3 | 38 | 1 | 0 | 38 | 0 | 100 | 0.0 | 100.0 |
| 4 | 37 | 1 | 0 | 37 | 0 | 100 | 0.0 | 100.0 |
| Mean | 39 | 1 | 0 | 38 | 1 | 100 | 1.3 | 98.7 |
| SD | 1.5 | 0 | 0 | 1.3 | 0.5 | 0 | 1.1 | 1.1 |

Abbreviations: BS, broken seeds; CP, cracked pods; CW, cracked whole seeds; DE, decorticating efficiency; NS, number of seeds; SBR, seed breakage ratio; SD, standard deviation; UP, uncracked pods; WSR, whole seeds recovery.

**TABLE 4** Results of performance of machine for processing five pods

| S/N | NS | CP | UP | CW | BS | DE (%) | SBR (%) | WSR (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 187 | 5 | 0 | 184 | 3 | 100 | 1.6 | 98.4 |
| 2 | 184 | 5 | 0 | 182 | 2 | 100 | 1.1 | 98.9 |
| 3 | 179 | 5 | 0 | 176 | 3 | 100 | 1.7 | 98.3 |
| 4 | 182 | 5 | 0 | 178 | 4 | 100 | 2.2 | 97.8 |
| Mean | 183 | 5 | 0 | 180 | 3 | 100 | 1.6 | 98.4 |
| SD | 2.6 | 0 | 0 | 2.8 | 0.6 | 0 | 0.3 | 0.3 |

Abbreviations: BS, broken seeds; CP, cracked pods; CW, cracked whole seeds; DE, decorticating efficiency; NS, number of seeds; SBR, seed breakage ratio; SD, standard deviation; UP, uncracked pods; WSR, whole seeds recovery.

The WSR was between 97% and 100% when single pods and multiple pods are cracked. For cracking single pods, the average WSR is 98.7 ± 1.14%. For multiple pods, the average WSR is 98.4 ± 0.35%. There is no significant difference in the WSR between feeding a single pod and feeding multiple pods. Kumar et al[53] obtained whole kernel recovery of 62.71% for a sal fruit decorticator. Sharm et al[54] had a whole kernel recovery of 52.24% for a fruit decorticator. Pradhan et al[55] also obtained whole kernel recovery of 67.94% for jatropha fruit decorticator.

The average SBR of *Delonix regia* seed from the machine was 1.6% when multiple pods were fed. Oluwole et al[28] obtained no breakage of nuts for a shea nut cracker. Kernel breakage was 30% for a cashew nut shelling machine by Ojolo et al.[18] Jain and Kumar[51] observed that increasing screw speed could result in high kernel breakage and, consequently, low whole kernel recovery. Ogunsina and Bamgboye[56] also noted that whole kernel recovery of cashew nuts may be influenced by the sizes of seeds.

For the feed rate of 5 pods in 30 seconds, the throughput of the machine was 56.4 kg/h. The feed rate or throughput was within the range of observed feed rates of decorticating and shelling machines by Kabir and Fedele,[42] which was between 3 kg/h to 215.8 kg/h. An increase in feed rate did not affect the efficiency of the machine. However, Gupta and Das[57] and Subramanian et al[49] observed that feed rate decreased with increase in dehulling efficiency for sunflower seed. Contrarily, Ranjeet and Sukhdev[58] found that decorticating efficiency increased with feed rate.

## 5 | CONCLUSION

*Delonix regia* is a tropical tree with seeds that find applications in medicine, nutrition, and energy. The manual process of separating the seeds from the pods of *Delonix regia* is tedious, slow, and unsafe. Mechanization of the process, to increase productivity and eliminate the drudgery, would be of value to its utilization for food, feed, or fuel purposes. In this study, compressive strength tests were carried out on *Delonix regia* pods in different orientations to determine the force required to fracture the pods. In addition, a decorticating machine that is capable of separating the seeds from the pods was designed. and a prototype of the machine was developed and evaluated.

The study established that the average force required to fracture the *D. regia* pods in the transverse orientation was 602 N. The average force required to fracture the pods in longitudinal orientation was 20 N. The maximum force required to fracture the pod was found to be 1360 N. The forces were taken into consideration during the design of the decorticating machine for *D. regia*. The efficiency of the decorticating machine was 100.0%. The machine had a power rating of 6 kW, and the whole seed recovery was estimated to be 98.4%. The throughput of the machine was 56.4 kg/h.

With the developed decorticating machine, the utilization of seeds of *D. regia* in medicine, human nutrition, and animal feeds will be further enhanced. In addition, the machine will eliminate the drudgery associated with the processing of large quantities of seeds required for energy applications. Further work will be carried out to investigate the effects of varying process parameters such as the moisture content of pods and beater speed, on the performance of the machine.

### CONFLICT OF INTERESTS

Authors have no conflict of interest relevant to this article.

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## AUTHOR CONTRIBUTIONS

Sunday Ojolo, Conceptualization-Equal, Investigation-Equal, Methodology-Equal, Supervision-Equal, Writing-review & editing-Equal; Joseph Orisaleye, Investigation-Equal, Methodology-Equal, Writing-review & editing-Equal; Adebayo Ogundare, Investigation-Equal, Methodology-Equal, Writing-review & editing-Equal; Damilola Kadiri, Investigation-Equal, Methodology-Equal, Writing-original draft-Equal.

## ORCID

*S. J. Ojolo* https://orcid.org/0000-0002-4548-0090
*J. I. Orisaleye* https://orcid.org/0000-0002-8793-3043
*A. A. Ogundare* https://orcid.org/0000-0003-3523-8214

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