



# Design and development of cashew nut shelling machine

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## Abstract

**Purpose** – The purpose of this paper is to investigate the physical and mechanical characteristics of the roasted cashew nut during fracture, by subjecting the nut to varying impact load tests at different orientations to ascertain the critical impact load that fractures the shell without damaging the kernel within. This load value was correlated with other parameters; shell/kernel moisture content level, average nut mass, to determine the required projection velocity to achieve this force. This projection velocity is the critical factor in sizing and design of the optimum configurations of the shelling impeller.

**Design/methodology/approach** – Mechanical properties of roasted cashew nut were first determined to know their fracture points. Each component of the shelling machine was designed. The components were assembled and the machine was tested for performance.

**Findings** – Machine throughput capacity was determined as 15.57 kg/h; shelling efficiency was 95 per cent; and whole kernel recovery was 70 per cent.

**Practical implications** – The efficiency in terms of whole kernel recovery could be improved by improving the pretreatment measures on the nuts.

**Originality/value** – The paper presents a machine which is affordable to peasant farmers and requires little or no training for operation and maintenance. The advantage of reduced unit cost can be derived from large-scale commercial production of this sheller.

**Keywords** Agriculture, Nuts (food), Impact strength, Production equipment

**Paper type** Research paper

## 1. Introduction

Cashew, *Anacardium occidentale*, is held in great esteem in many customs and cultures (Azam-Ali and Judge, 2004). It is a resilient and fast-growing evergreen tree that can grow to the height of about 20 m (Davis, 1999). The cashew apple is a pseudocarp, and in biological terms, is the thickened stem of a fruit which the actual fruit, the cashew nut, is attached. It is known to originate from South and Central America, that is, from Brazil to Mexico (Nurland, 2000; Davis, 1999). Around the nineteenth century, plantations were developed, and the trees spread to a number of countries in Africa, Asia and Latin America (Mandal, 2002; Azam-Ali and Judge, 2004). The cashew trees have been used to prevent erosion. The cashew nuts and fruit contribute in various ways to local livelihood: they are good sources of nutrition and the tree has other uses, including medicines and construction (Nazneen, 2004). The cashew nut is one of the most valuable processed nuts on global commodity markets, being also an important cash crop for farmers. It has the potential to generate employment through processing and export revenue for developing countries (Nazneen, 2004).

Three main cashew products are traded on the international market – raw nuts, cashew kernels and cashew nut shell liquid (CNSL). The cashew apple, being a fourth product, is consumed locally (Azam-Ali and Judge, 2004).



The raw cashew nuts, though eight to ten times less than the weight of the cashew apple, is the main commercial product of the cashew tree. The raw nuts are either exported or processed prior to export. The cashew nut is also a popular dessert nut, eaten out of hand, with other mixed nuts. It is also made into cashew butter and nut milk, and used in baking and confectionaries (Davis, 1999; Rosengarten, 1984). Processing of the raw nuts releases the by-product CNSL that has industrial and medicinal applications (DermNet, 2007; Davis, 1999). The skin of the nut is high in tannins and can be recovered and used in tanning of hides. The fruit of the cashew tree surrounds that kernel can be made into a juice with a high vitamin C content and fermented to give a high proof of spirit (Azam-Ali and Judge, 2004; Davis, 1999; Nатурland, 2000; Calvalante *et al.*, 2005).

Data as at 2000 reveals that the cashew industry ranks third in the world production of edible nuts, and also that Africa produced about 35.6 per cent of the total cashew produced globally, with Nigeria contributing about 40.7 per cent of this (Azam-Ali and Judge, 2004). However, bulk of the harvested nuts has gone to India and other countries in Asia where there is a large processing capacity (Adetumbi, 2001). This is because of the low processing capacity for cashew nut in Nigeria (Ogunsina and Odugbenro, 2005).

Traditionally, extraction of the kernel from the shell of the cashew nut has been a manual operation (Intermediate Technology Development Group (ITDG), 2002). The nuts are kidney shaped and brittle which makes it difficult to remove the shell without breakage. The most significant difficulty in processing cashew nuts is that the shell, which contains a caustic oil, CNSL, which can burn the skin and produce noxious fumes when heated (Nazneen, 2004). During the traditional method, sun-dried nuts are first dunked briefly in water, and then roasted over fire in pans with holes in them while being stirred constantly to prevent the nuts from burning. This method is called open pan roasting. The shells break open during the process, whereby some of the cashew nut shell oil drips out through the holes and into the fire. The split-open shells are collected in ash or sawdust to soak up the rest of the oil (Nатурland, 2000; Davis, 1999; Azam-Ali and Judge, 2004; ITDG, 2002).

Another possibility is to roast the nuts in a wood-fired roasting oven, also called drum roasting. There is no conditioning such that the CNSL is not removed from the shell, and can be used as industrial oil. The nuts are roasted for so long until the shells are completely brown to black, else there is the danger that the shells will be difficult to break open, and that seeds may become damaged (Nатурland, 2000; National Seed Industry Council (NSIC), 2005; Nazneen, 2004; ITDG, 2002; Tasiwal, 2008). The oil bath roasting, where sun-dried nuts are placed in wire baskets and dipped into baths containing hot cashew nut shell oil at about 200°C for 90 seconds, is also used. The shell become brittle, and some of the CNSL can flow into the oil bath. The baskets are finally removed to let the oil drip back into the bath and the nuts are dried (Nатурland, 2000; Davis, 1999; ITDG, 2002; Tasiwal, 2008). Steam roasting involves treating the raw cashew nuts in a pressurized cooker filled with steam for about 15 minutes. The treated nuts are then spread out on the floor for cooling and then sent to the shelling section (Tasiwal, 2008; NSIC, 2005; Nazneen, 2004). After shelling comes drying, peeling, grading and packaging.

Shelling is the removal of dry roasted shell and has an objective of producing clean, whole kernels free of cracks, as whole kernels have a better market value than broken kernels (ITDG, 2002; Nатурland, 2000). The manual shelling process involves placing the

roasted nuts on a flat stone and cracking with a wooden mallet or batten (ITDG, 2002; Azam-Ali and Judge, 2004; Nazneen, 2004; Davis, 1999; Naturland, 2000). An average sheller can open ten nuts per minute which amounts to 4,800 nuts or about 5 kg of kernels. Experienced shellers can produce only half as much, with a quality of 90 per cent whole kernels (ITDG, 2002). The manual traditional method of shelling cashew nut using hammer is a labour intensive, slow and tedious process. It also has some health implications due to the corrosive action of CNSL on human skin (Ojolo and Ogunsina, 2007; DermNet, 2007). Recently, roasted nuts have been cut by semi-mechanised shelling such as the impact-shelling machine (Nazneen, 2004).

The pedal-operated knife cutter (Ajav, 1996) has been developed. A semi-mechanised process that has been used in Brazil, uses a pair of knives, each shaped in the contour of half a nut had a daily production of about 15 kg of kernels (ITDG, 2002). A motorized cashew nut sheller developed by Jain and Kumar (1997) has a capacity of  $18 \text{ kg h}^{-1}$  and a shelling of 70 per cent and whole kernel yield of 50 per cent. Ojolo and Ogunsina (2007) developed a cashew nut cracking device with a capacity of 21 kg of kernels per day and whole kernel recovery of 67 per cent.

The challenge of designing and actualizing the successful fabrication of a motorized cashew nut shelling equipment should be accepted by engineers and investors as a result of the discovery of a dearth of mechanized system of cashew nut shelling in most cashew nut processing industries in many countries, especially in Nigeria. Therefore, this project is important because it will proffer solution to the drudgery associated with manual cashew nut shelling. The main objective of this work is to design and develop a motorized cashew nut shelling equipment and evaluate it for optimum performance.

## 2. Materials and methods

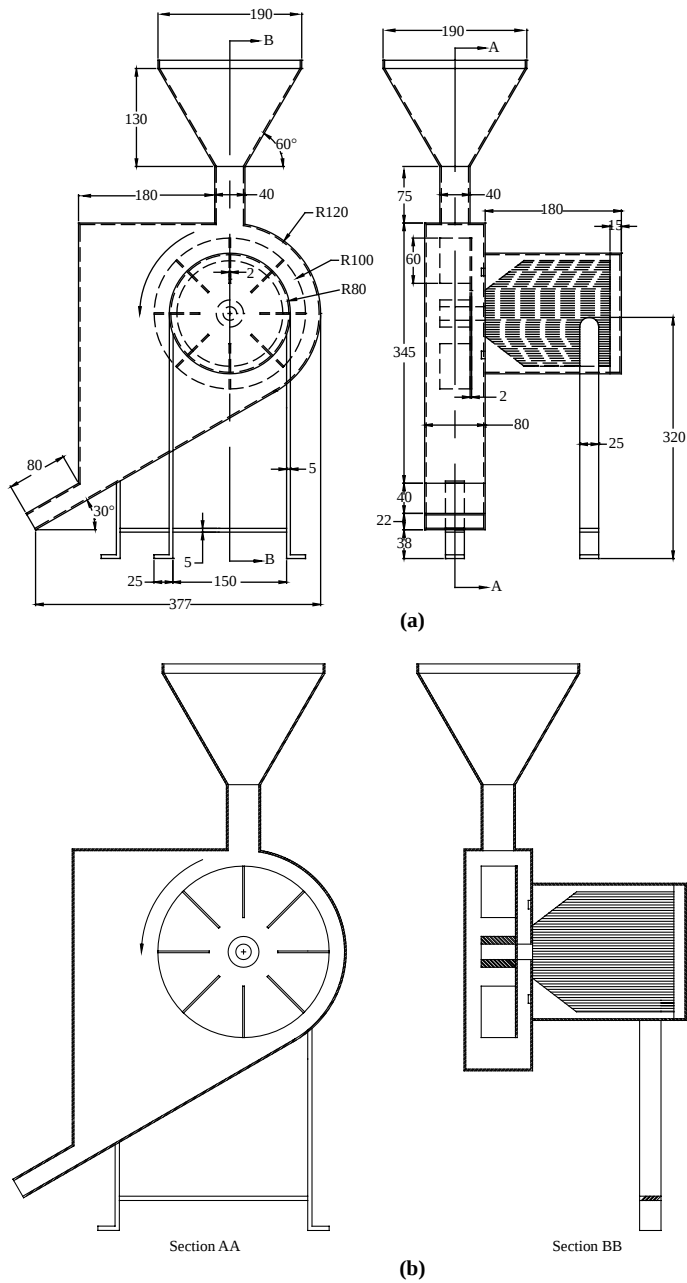
The machine designed is motorized. During operation, it cracks cashew nuts by impact when the nuts are hurled toward a fixed wall by an impeller which is driven by the electric motor. The fully assembled machine is shown in Figure 1(a) and (b).

Preliminary tests were first carried out to determine the moisture content of the cashew nut shell and kernel. Also, impact load tests were carried out to determine the fracture characteristics of the nuts.

### 2.1 Preliminary tests

*2.1.1 Moisture content tests.* Before the cashew nuts were subjected to the impact load tests, the moisture contents of the nuts were determined using the oven method. The procedure used in determining the moisture content is:

- Two samples, each of shell and kernel from a roasted cashew nut, were ground to almost fine flour individually.
- The initial weight of each sample was determined.
- The samples (each in a can) were placed in an oven and dried at a temperature of  $130\text{--}135^{\circ}\text{C}$  for 1 h.
- The samples were removed from the oven and then cooled at room temperature in a dessicator.
- The final weights of the samples were determined.
- The test was repeated each for four other pair of samples of shell and kernel from roasted cashew nuts.



**Notes:** (a) The cashew nut shelling machine; (b) sectional views of the assembled cashew nut shelling machine

**Figure 1.**

The percentage moisture content was then determined using:

$$\% \text{ Moisture content} = \frac{(\text{weight before drying} - \text{weight after drying})}{\text{weight before drying}} \times 100$$

The findings and results are presented in Table I.

*2.1.2 Impact load tests.* The orientation of the cashew nuts in relation to the impeller vane prior to impact could not be fixed due to the tumbling action of the nuts through the feed hopper chute. Fracture characteristics, that is resistance to impact forces, of the cashew shell, at different orientations of the cashew nut, were determined by impact load tests. The tests were uniaxial impact load tests with each nut carefully aligned on the equipment. The results are presented in Table II which indicated that the lateral orientation, compared to other orientations of the cashew nut, required the least amount of force (67.4 N) to fracture the shell. A force of 108.8 N was required to fracture the nutshell in the dorsal orientation – which was the highest impact force and it was presupposed that it was the critical force that should be applied to effectively fracture the shell. This pattern of deformation and fracture was similar to what had been observed for cocoa pods by Maduako and Faborode (1994), Faborode and Dinrifo (1994); and for other agricultural products, especially grains and eggshells (Mohsehin, 1980; Reece and Lott, 1976).

*2.2 Design analysis*

*2.2.1 Design of impeller and shaft.* The shell of the cashew nut cracks plastically under impact load, implying that there is no conservation of kinetic energy. In impact loading, the velocity is the required parameter.

**Table I.**  
Moisture contents  
of cashew nut  
shell and kernel

| Weight of shell<br>before drying | Weight of shell<br>after drying | Moisture<br>content | Weight of kernel<br>before drying | Weight of kernel<br>after drying | Moisture<br>content |
|----------------------------------|---------------------------------|---------------------|-----------------------------------|----------------------------------|---------------------|
| 1.85                             | 1.70                            | 0.16                | 1.31                              | 1.30                             | 0.09                |
| 1.23                             | 1.01                            | 0.22                | 1.48                              | 1.40                             | 0.08                |
| 2.15                             | 1.99                            | 0.16                | 1.38                              | 1.32                             | 0.08                |
| 2.20                             | 2.01                            | 0.19                | 1.39                              | 1.30                             | 0.09                |
| 2.45                             | 2.20                            | 0.15                | 1.90                              | 1.80                             | 0.10                |

**Notes:** Mean shell moisture = 12.34 per cent; mean kernel moisture = 5.87 per cent

**Table II.**  
Fracture points of roasted  
cashew shell under  
impact loads

| Experiment number | Longitudinal (N) | Dorsal (N) | Lateral (N) |
|-------------------|------------------|------------|-------------|
| 1                 | 90.0             | 109.0      | 68.0        |
| 2                 | 88.0             | 102.0      | 70.0        |
| 3                 | 86.0             | 106.0      | 72.0        |
| 4                 | 70.0             | 107.0      | 65.0        |
| 5                 | 72.0             | 108.0      | 66.0        |
| 6                 | 75.0             | 115.0      | 67.0        |
| 7                 | 78.0             | 107.0      | 69.0        |
| 8                 | 77.0             | 110.0      | 71.0        |
| 9                 | 80.0             | 111.0      | 63.0        |
| 10                | 85.0             | 113.0      | 63.0        |

To calculate the velocity of impact:

$$\text{Impact energy} = \text{kinetic energy}$$

Sharma and Aggarwal (2006):

$$\text{Impact energy} = \frac{mv^2}{2} \text{J}$$

The average mass of the nut is 3.7 g:

$$\text{Impact energy} = \frac{0.0037v^2}{2} \text{J}$$

$$\text{Impact energy} = 0.00185v^2 \text{J}$$

Assuming that the colliding force of the nut with the shelling wall is entirely plastic in nature, then:

$$\text{Impact energy} = \text{work of deformation}$$

Sharma and Aggarwal (2006), where:

$$\text{work of deformation} = 0.5F \times e \text{J}$$

Sharma and Aggarwal (2006).

And  $F$  is the applied force and  $e$  is the deformation:

$$F = P \times \frac{f'}{f} \text{ N}$$

$$F = P \times \frac{e'}{e} \text{ N}$$

where  $f'$  and  $e'$  are the stress and deformation under impact, respectively; and  $f$  and  $e$  are direct stresses and corresponding deformation, respectively; and  $P$  is the load applied in impact and is equal to the impact load required to shell the nut (Sharma and Aggarwal, 2006).

But:

$$f' = 2 \left( \frac{P}{A} \right) \text{N/m}^2$$

implying that:

$$f' = 2f$$

and:

$$e' = 2e$$

Hence:

$$F = 2P$$

work of deformation is thus:

$$\text{Work of deformation} = P \times e \text{J}$$

The mean impact load of 108.8 N, corresponding to the force required to shell at the dorsal end, is used:

$$\text{Work of deformation} = 108.8eJ$$

$e$  is the maximum deformation of the nut taken to be the difference in the sizes of the shell and the nut. This is obtained by the average of differences obtained from Ojolo and Ogunsina (2007):

$$e = 7.25 \text{ mm}$$

$$e = 0.00725 \text{ m}$$

Hence:

$$\text{Work of deformation} = 108.8 \times 0.00725 J$$

$$\text{Work of deformation} = 0.79 J$$

Equating to the kinetic energy:

$$0.00185v^2 = 0.79$$

$$v^2 = \frac{0.79}{0.00185}$$

$$v^2 = 427.03$$

$$v = 20.67 \text{ ms}^{-1}$$

The motion, in the absence of the obstructing shelling wall, of the nut when hurled by the impeller is that of a projectile. Thus, the velocity of motion in the horizontal direction is uniform and has no component of acceleration. Hence, the velocity of impact equals the tangential velocity of the impeller. Therefore, if an impeller of diameter 200 mm is selected, then, the angular speed of impeller is:

$$v = \omega r \text{ ms}^{-1}$$

$$\omega = \left(\frac{v}{r}\right) \text{ rad s}^{-1}$$

$$\omega = \left(\frac{20.67}{0.1}\right) \text{ rad s}^{-1}$$

$$\omega = 206.7 \text{ rad s}^{-1}$$

$$\omega = 2\pi N \text{ rad s}^{-1}$$

The speed in revolutions per minute is:

$$N = \frac{\omega}{(2\pi)}$$

$$N = \frac{206.7}{(2\pi)}$$

$$N = 32.90 \text{ rev/s}$$

$$N = 1973.84 \text{ rpm}$$

The radius of gyration is:

$$k = \frac{D}{4}$$

Shigley and Uicker (2002):

$$k = \frac{0.2}{4}$$

$$k = 0.05 \text{ m}$$

The equivalent mass of the body referred to the line of action of the tangential force, is given by:

$$m_{\text{eq}} = m \left( \frac{k}{r} \right)^2$$

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$$m_{\text{eq}} = 0.08 \times \left( \frac{0.05}{0.1} \right)^2$$

$$m_{\text{eq}} = 0.02 \text{ kg}$$

The tangential force, where  $a$  is the linear acceleration, is:

$$F = m_{\text{eq}} a$$

Roytech (2008):

$$F = m_{\text{eq}} \omega^2 r$$

$$F = 0.02 \times (206.7)^2 \times 0.1 \text{ N}$$

$$F = 85.45 \text{ N}$$

The torque required for the rotation is:

$$T = Fr$$

$$T = 85.45 \times 0.1 \text{ Nm}$$

$$T = 8.5 \text{ Nm}$$

The minimum power required is:

$$P = T\omega$$

$$P = 8.5 \times 206.7$$

$$P = 1,757 \text{ W}$$

Hoop stress, being an approximation for the centrifugal stress acting on the rotating impeller, is:

$$\sigma_{\theta} = \rho \omega^2 r^2 = \rho v^2$$

Singh (2008):

$$\sigma_{\theta} = \rho \times (20.67)^2$$

Taking  $\rho$  to be  $7,830 \text{ kg m}^{-3}$ :

$$\sigma_{\theta} = 3.35 \text{ MPa}$$

If hoop stress equals the torsional stress transmitted to the shaft, then:

$$\tau = 3.35 \text{ MPa}$$

But:

$$\tau = \frac{Tr}{J}$$

$$3.35 \times 10^6 = 8.5 X \left\{ \frac{r}{(\pi r^4 / 2)} \right\}$$

$$394,117 = \frac{2}{\pi r^3}$$

$$619,078 = \frac{1}{r^{-3}}$$

$$r = 0.0117 \text{ m}$$

$$r = 11.7 \text{ mm}$$

The required shaft diameter to be selected to drive the impeller at the specified power rating and speed is 25 mm.

*2.2.2 Feed hopper design.* The major parameter governing the size and configuration of the feed hopper is the throughput capacity of the machine. The hopper must be able to accommodate enough nuts to achieve the required throughput capacity and efficiency of operation. The feed angle of the hopper is configured to enable free flow of the nuts and ensure the system is self-cleaning. The stability of the sheller in operation has also been taken into consideration in sizing the hopper such that the weight of fed nuts in the hopper does not affect the balance of the sheller in operation. The feed hopper was made of steel and was designed to be detachable to enable utilization of different hopper size and also for convenience in moving and storing the sheller.

*2.2.3 Casing design.* The functional requirements of the casing are primarily to house the internal components of the sheller, the shelling impeller, the drive motor, and to ensure easy passage for the nuts to be shelled and exit of the shelled kernels.

### 2.3 Testing and performance evaluation

The sheller was tested and its performance was evaluated by the shelling efficiency, whole kernel recovery and throughput. The results of the test are presented in Table III. The feeding efficiency was found to be dependent on the feeding rate (nuts/minute) which in turn determined the throughput of the sheller. When the hopper was filled, with the nuts falling through the chute under gravity gave impressive results. Some nuts, however, got stuck at the throat of the chute.

Manual feeding at a rate of two nuts every second or 120 nuts per minute produced an overall throughput capacity of 23 kg of nuts per hour.

The shelling efficiency was evaluated by:

$$\text{Shelling efficiency} = \frac{\text{completely shelled nuts (average)}}{\text{total feed}} \times 100\%$$

The whole kernel recovery was evaluated by:

$$\text{Whole kernel recovery} = \frac{\text{whole kernels recovered (average)}}{\text{total feed}} \times 100\%$$

The throughput was evaluated by:

$$\text{Throughput (kg/h)} = \text{mass} \times \text{selling rate} \times 1 \text{ h}$$

with shelling rate evaluated as:

$$\text{Shelling rate} = \frac{\text{completely shelled nuts}}{\text{shelling times}}$$

### 3. Results and discussions

#### 3.1 Results

$$\text{Shelling efficiency} = \frac{49}{50} \times 100\%$$

$$\text{Shelling efficiency} = 95\%$$

$$\text{Whole kernel recovery} = \frac{35}{50} \times 100\%$$

$$\text{Whole kernel recovery} = 70\%$$

$$\text{Throughput} = \frac{48}{25} \times 3,600 \text{ nuts/h}$$

$$\text{Throughput} = 6,912 \text{ nuts/h}$$

$$\text{Throughput} = 15.57 \text{ kg/h}$$

#### 3.2 Discussions

The shelling efficiency was evaluated on the basis of the number of completely shelled nuts per batch of 50 nuts. Results indicated that out of every 50 nuts an average of 48 nuts were completely shelled, thus giving a shelling efficiency of 95 per cent; this is higher

| Test | Number of nuts fed into the sheller | Completely shelled nuts | Whole kernels recovered | Broken kernels recovered | Shelling time (s) |
|------|-------------------------------------|-------------------------|-------------------------|--------------------------|-------------------|
| 1    | 50                                  | 48                      | 40                      | 10                       | 25                |
| 2    | 50                                  | 47                      | 34                      | 16                       | 25                |
| 3    | 50                                  | 49                      | 36                      | 14                       | 25                |
| 4    | 50                                  | 50                      | 32                      | 18                       | 25                |
| 5    | 50                                  | 46                      | 33                      | 17                       | 25                |
| Mean | 50                                  | 48                      | 35                      | 15                       | 25                |

**Table III.**  
Results from testing of  
the cashew nut sheller

than 70 per cent obtained by Jain and Kumar (1997) for motorised sheller. The whole kernel recovery, evaluated on the basis of the number of kernels recovered unbroken out of every batch of 50 nuts shelled, indicated that a mean number of 35 nuts out of every 50 nuts were recovered whole. The whole kernel recovery was 70 per cent. The shelling efficiency of the cashew nut sheller has a higher shelling efficiency than that obtained from the manual sheller by Ajav (1996) which was 67-75 per cent, and a manual cashew nut cracking device by Ojolo and Ogunsina (2007). The whole kernel recovery was higher than 50 per cent obtained by Jain and Kumar (1997) for a semi-automated sheller and 67 per cent that was obtained by Ojolo and Ogunsina (2007) for a manual cashew nut cracking device. The throughput (15.475 kg/h) is much higher than 21 kg of nuts/day (that is, 0.875 kg/h) achievable by manual shelling of nuts using a mallet or batten (Azam-Ali and Judge, 2004). Optimum processing and pre-shelling treatments also play a vital role in the shelling characteristics of cashew nut (Thivavarnvongs *et al.*, 1995).

### Conclusions

A cashew nut sheller has been designed to improve the efficiency of the shelling operation as a means of processing of the cashew nut. The average shelling efficiency of the machine is 95 per cent while whole kernel recovery is 70 per cent. The machine performed satisfactorily and can still be modified for better performance, in order to improve the kernel whole recovery, and the manufacturing cost. This could be done by extensive study on the pretreatment characteristics of the kernel. The advantage of reduced unit cost can be derived from large-scale commercial production of this sheller.

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