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DEVELOPMENT AND PERFORMANCE EVALUATION OF FLUTED PUMPKIN SEED DEHULLING MACHINE

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Abstract

A machine for dehulling fluted pumpkin seed (*Telfairia occidentalis*) was developed. The main objective of developing the machine was to provide a better substitute to traditional methods of dehulling the seed which contains edible oil of high medicinal and nutritional values. Traditional methods are full of drudgery, slow, injury prone and would lead to low and poor outputs in terms of quantity and quality of dehulled products. The machine is made of five major parts: the feed hopper (for holding the seeds to be dehulled before getting into the dehulling chamber), dehulling chamber (the part of the machine that impacts forces on seeds thereby causing fractures and opening of seeds coats for the delivery of the oily kernels), discharge unit (exit for oily kernels and seed coats after dehulling), the frame (for structural support and stability of all parts of the machine) and electric motor (power source of the machine).The development process involved design of major components (shaft diameter (20 mm), machine velocity (7.59 m/s), power requirement (3hp single phase electric motor) and structural support of $45mm \times 45mm \times 3mm$ mild steel angle iron), selection of construction materials and fabrication. ANSYS R14.5 machine design computer software was used to design the shaft and structural support; while other components were designed with conventional design method of using design equations. The machine works on the principle of centrifugal and impact forces. Performance evaluation was carried out after fabrication and 87.26%, 2.83g/s, 8.9% and 3.84%were obtained for dehulling efficiency, throughput capacity, percentage partially dehulled and percentage undehulled respectively.

Keywords: fluted pumpkin seed, development, cracking efficiency, throughput capacity, working principle.

1.Introduction

Fluted pumpkin (*Telfairia occidentalis*) plant is a tropical vine grown in West Africa as a leafy vegetable and for its edible seeds. The common names for the plant are fluted gourd, fluted pumpkin, and *ugu* (Badifu *et al.*, 1995). It belongs to the family *Curcubitaceae* and has a simple, dark green veined leaf that is18cm wide and 35cm long (Esquinas-Alcazar and Gulick, 1983). The plant has the widest diversity in terms of variation in pod and seed colour, seed and plant vigour, anthocyanin content of leaves and petioles or shoots and leaf size (IPGRI, 1999). Seeds of fluted pumpkin are enclosed inside the pods of the plant (Figure 1), Odewole *et al.*, (2015a) reported the description of the pod and other useful information. Odewole *et al*., (2015b) reported that the oily kernels of fluted pumpkin seeds contain vitamin E, vitamin A, zinc and essential fatty acid. The oil is also good for maintaining healthy blood vessels, nerves and tissues and can be used to treat prostrate and bladder problems in man. Odewole *et al.,* **(**2015a) reported some mechanical properties of three varieties of fluted pumpkin seeds necessary for the design of cracking machine.

(a)

(b)

Figure 1: Fluted pumpkin pods (a) and seeds (b) Source: Odewole *et al*., (2015b)

Dehulling (as applicable to this type of seed)is the formation of fractures on the outer surface of seed coat through the application of force with the overall aim of recovering some needed materials after cracking. This action will cause division of materials into different components. Some of the forces that are used to achieve this action include centrifugal, impact, compression, attrition or their combinations (Odewole and Ajibade 2015). Dehulling is necessary in processing of some agricultural materials in order to be able to utilize them fully or rather to remove some unwanted material. To be able to get the oily kernels in fluted seeds and utilize its oil for other useful purposes, dehulling is one of the important postharvest operations that must be done. However, the traditional method of dehulling seeds is full of drudgery, slow, injury prone, unhygienic, and normally leads to low and poor outputs in terms of quantity and quality of product. Therefore, the objectives of this work were to develop a mechanical dehulling machine and carry out its performance evaluation in terms of dehulling efficiency, throughput capacity, percentage partially dehulled and percentage undehulled.

2. Materials and Methods

2.1. Design Considerations

In designing the fluted pumpkin seed dehulling machine, the following factors were considered: force to dehull the seed with minimum damage to the kernel (determined to be 53.5 N by Odewole *et al*., 2015a), power requirement and structural stability of the machine.

2.2. Shaft Design

The horizontal shaft of the machine was designed with ANSYS (2010) R14.5 version of machine design software. Figure 2 shows the free body diagram of the designed shaft. Points A and B are fixed to the frame of the machine. Point C is the force acting (6.87 N) on the shaft from the electric motor, while forces on points D (10.85N) and F(10.00N) are due to the action of the roller bearings on the shaft. The force on point E (27.72 N) is the value for the three plates on thick plates of the shaft and that of seeds to be cracked. The shear force and bending moment diagrams from the ANSYS software are shown in Figure 3. The maximum shear force of 20.54 N (0.3 m of the shaft's full length) occurred at point E. Maximum bending moment of 1.85 Nm occurred at point D (0.45 m of the shaft's full length). After using different specifications of solid cylindrical mild steel metal, the design that gave safely carried all the specified loads was 20 mm solid cylindrical mild steel.

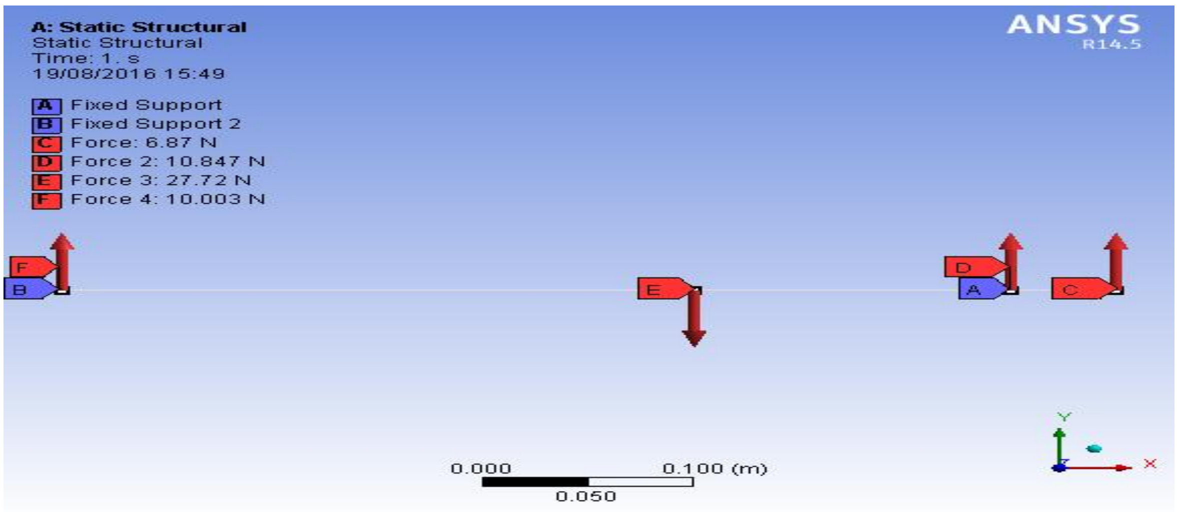


Figure 2: Free body diagram of designed shaft

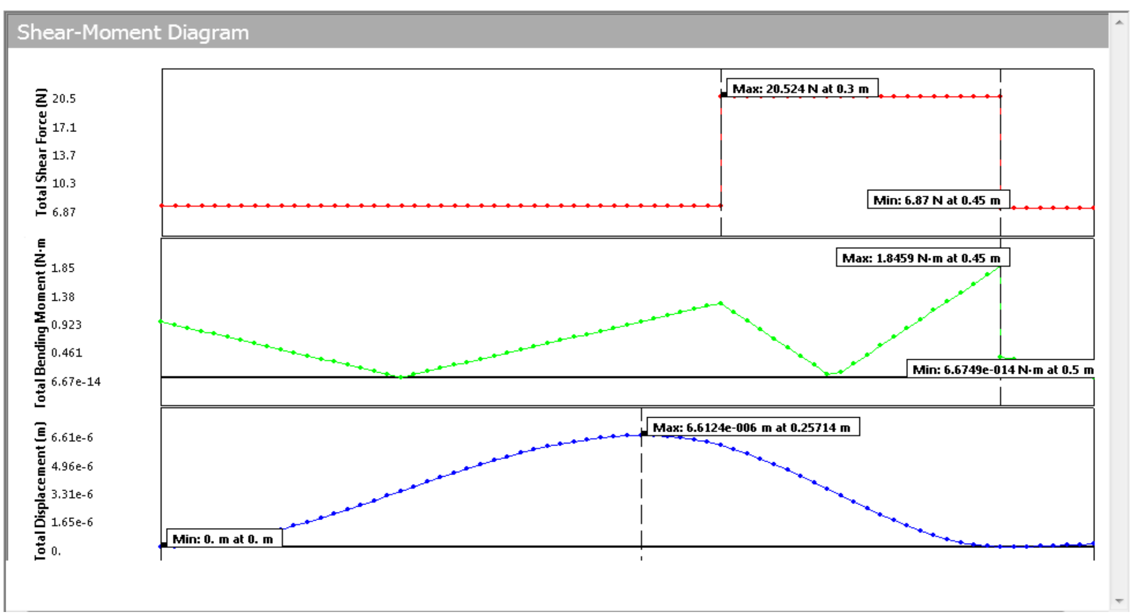


Figure 3: Shear force and bending moment diagram of shaft

2.3. Pulley Design

All the designs in this section were according to the procedures given in Odewole and Ajibade (2015).

$N_1 D_1 = N_2 D_2$ (1)

Assumed diameter of electric motor pulley, D_1=100 mm; diameter of the dehuller's pulley = D_2; speed of electric motor (medium) N_2=1450 rpm, assumed speed of the dehuller = 900 rpm; using equation (1), D_2 =161.11 mm

2.4. Power Required for Operating the Machine

Power $= P_f + P_m + P_p + P_c$(2)

Where, P_f =Power to overcome inertia. P_m = Power to rotate moving parts. P_p =Power to convey seeds to be cracked. P_c = Power to crack seeds

$P_f = W \times V$(3)

$$V = \frac{\pi D_2 N_2}{60} = 7.59 m/s$$

where: V = Driven shaft speed.

$W = W_D + W_T + W_S + W_P$(4)

Where, W =Total weight, W_D =weight of Plates on the shaft, W_T =weight of thread

W_P = weight of the driven pulley, $W\ was\ assumed\ to\ be$ $73.56\ N$, $P_f = 558.32\ W$

P_f since the power to overcome inertia will also rotate the moving part

$P_p = WSOT \times V$ (5)

where: $WSOT$ = weight of seed on the blades, $P_p = 189.75\ W$

$P_c = TFC \times V$(6)

where:TFC(dehulling force from UTM) $= 53.5N$ (Odewole *et al*., 2015b), therefore,

$$P_c = 406.07\ W$$

Total Power $= 558.32 + 558.32 + 189.75 + 406.07 = 1712.46\ W$

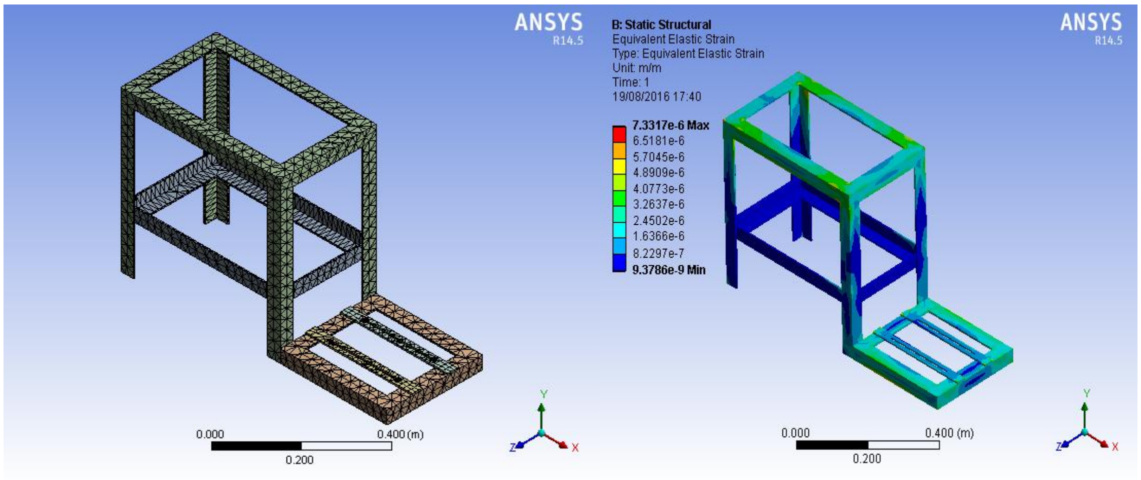
Power to operate the machine = Total power/assumed efficiency (7)

$$\frac{1712.46}{0.80} = 2140.56\text{ W} = 2.141\text{ kW} = 2.82\text{ hp}$$

A single phase electric motor of approximately 3 hp was considered safe for the machine.

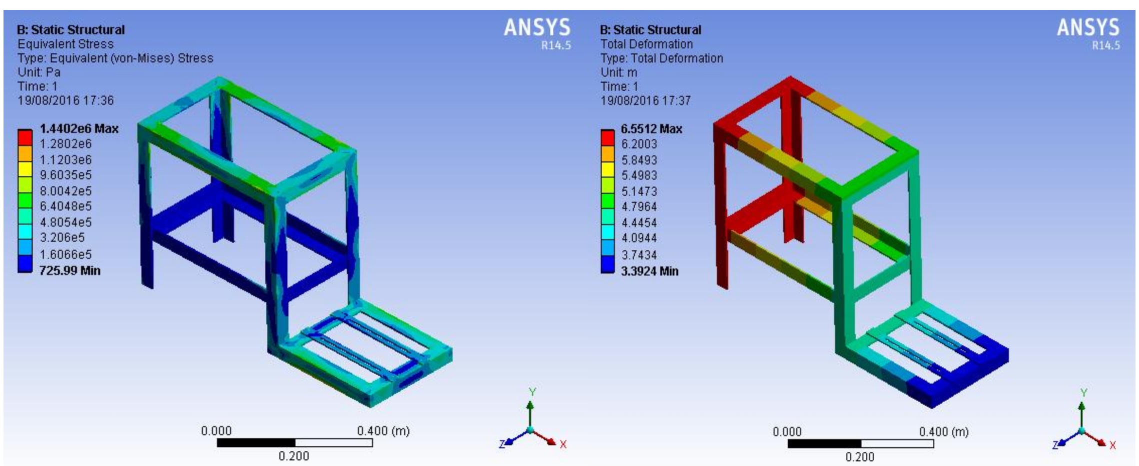
2.5. Design of Structural Support (frame)

The ANSYS R14.5 was also used to design the frame that will safely withstand all the loads on the machine. Figures 4 and 5 show the mesh, Static Structural Equivalent Strain, stress and deformation analyses of the frame. The nodes (points where lines met) were where strain, stress and deformation analyses were individually carried out for proper design of the frame. From the colour code on the scales on Figures 6,7 and 8, the maximum strain (deep green), stress (deep green) and deformation (red) that can occur on the frame were $3.26 \times 10^{-6} m/m$, $6.40 \times 10^{5}\ N/m^{2}$ and 6.55 m respectively. The dimension of angle iron that safely carried all loads and shocks was $45mm \times 45mm \times 3mm$ mild steel.



(a) (b)

Figure 4: Mesh (a) and strain (b) analysis of machine tool frame



(a) (b)

Figure 5: Stress (a) and deformation (b) analysis of machine tool frame

2.6. Machine Fabrication

Figure 6 shows the pumpkin seed dehulling machine after fabrication and assembly. Mild steel sheet was used to fabricate all the parts of the machine. For the structural support (frame), mild steel angle iron with dimension $45mm \times 45mm \times 3mm$ was used all through; and mild steel sheet of thickness 3 mm was used for the hopper and the discharge unit, 5 mm mild steel was used for the dehulling chamber. All the dimensions were marked out, cut, turned, welded and assembled according to designed specifications.

Figure 6: Fabricated dehulling machine

2.7. Machine Description and Working Principle

Figure 7 shows the orthographic projection of the fluted pumpkin dehuller. The machine is divided into five major parts namely: the feed hopper, dehulling chamber, discharge unit for the mixture of oily kernels and seed coats (chaffs), the frame and source of power (3 hp single phase electric motor). The hopper is conical in shape and it is on a pipe and placed on top of the dehulling chamber casing. The dehulling chamber has cylindrical cross section and consists of an internal horizontal solid shaft (20 mm) with three blades attached to it at 120º to each other. Driven pulley which takes power needed for dehulling from the electric motor via v-belt linkage and driving pulley of the electric motor is attached to one end of the shaft. At a short distance from the driven pulley, a roller bearing around the shaft is attached to the dehulling chamber and another roller bearing close to the other end of the shaft is used to hold the shaft to the dehulling chamber. All components of the machine are rigidly attached to the structural frame of the machine made of $45mm \times 45mm \times 3mm$ mild steel angle iron.

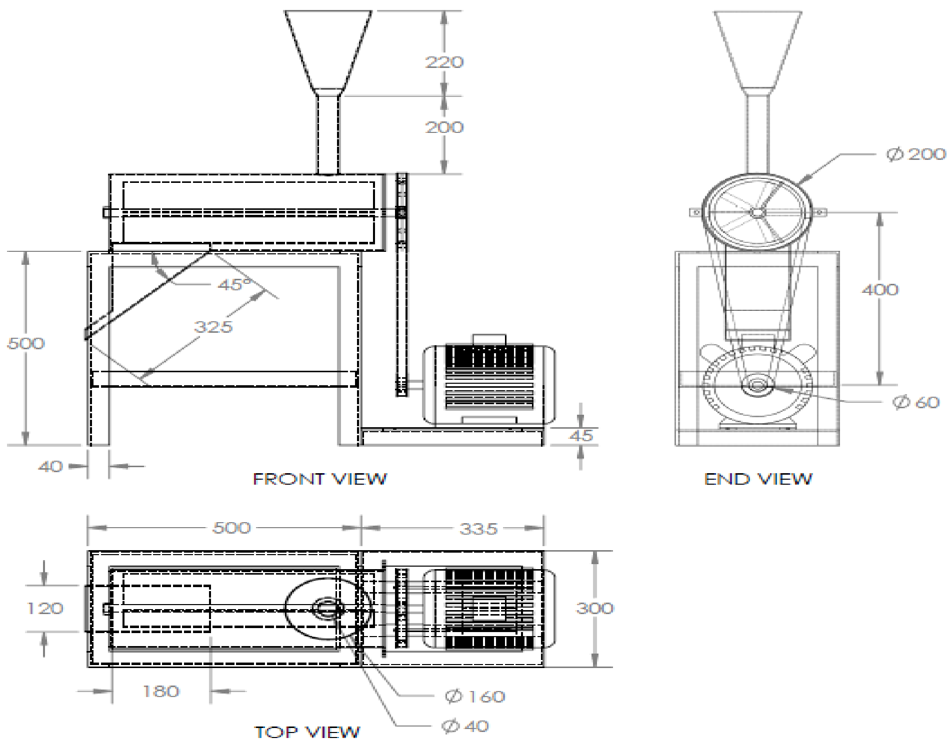
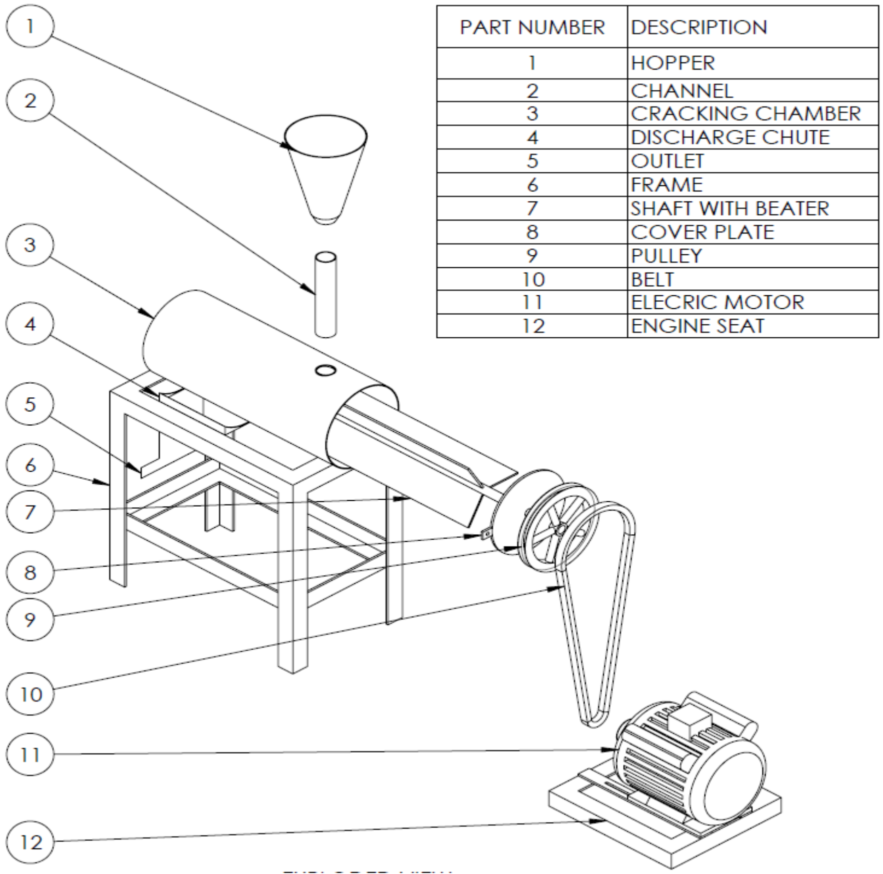


Figure 7: Orthographic projection of dehuller

The machine works on the principle of centrifugal force and impact force. When the seeds get into the dehulling chamber via the hopper, they are rotated vigorously (centrifugal force action) and hit against the hard surface (impact force action) of the dehulling chamber. The two actions would lead to formation of fractures that would later cause splitting of seeds for the liberation of the needed oily kernels. After dehulling, all materials (kernels, escaped whole seeds, partially dehulled seeds, seed coats) inside the dehulling chamber are discharged via the outlet; and separation of discharged materials into various components would be done manually. It is advisable to allow the machine to run empty for about 30 s before loading it with seeds to be dehulled. This action is a safety precaution that will not cause the starting current of the electric motor to increase; failure to do so might subject the electric motor to serious damage. The part list of the machine is shown in Figure 8.



PART NUMBER	DESCRIPTION
1	HOPPER
2	CHANNEL
3	CRACKING CHAMBER
4	DISCHARGE CHUTE
5	OUTLET
6	FRAME
7	SHAFT WITH BEATER
8	COVER PLATE
9	PULLEY
10	BELT
11	ELECRIC MOTOR
12	ENGINE SEAT

Figure 8: Exploded view of the dehuller showing working components and part list

2.8. Performance Evaluation of the Machine

The performance evaluation of the fabricated machine in terms of dehulling efficiency, throughput capacity, percentage partially dehulled and percentage undehulled was carried out. Fluted pumpkin pods of 13 weeks old (minimum harvesting age) were procured at National Horticultural Research Institute (NIHORT), Ibadan, Nigeria. The pods were broken manually for the recovery of seeds needed for the dehulling operation. The seeds were cleaned and fed into the machine via the hopper. The total mass of fluted pumpkin seed loaded into the machine was 900 g. Fifteen (15) runs were carried out on the machine; for each run, 60 g of fluted pumpkin were fed into the machine and the time taken to complete the dehulling was obtained using a stop watch (NOCAM ANDROID).

After dehulling, collected samples were grouped into various components (kernel, partially dehulled, shells and escaped whole seeds).The performance indices in terms of dehulling efficiency and throughput capacity are as stated and evaluated below:

Dehulling efficiency (%) $= \frac{MI-(MP+ME)}{MI} \times 100\%$ (Odewole and Ajibade 2015) (8)

Throughput capacity $T_c(g/s) = \frac{3.6M_C}{t}$ (Ghafari *et al.*,2011) (9)

$Percentange\ partially\ dehulled = \frac{MP}{M_C} \times 100$ (10)

$$Percentange\ undehulled = \frac{ME}{M_C} \times 100 \tag{11}$$

where: $M_C = M_i$ = mass of sample before dehulling (900 g), t = time used in dehulling (1150 s), *MP* is mass of partially dehulled (80.1g), *ME* is mass of undehulled seeds (34.60g).

3. Results and Discussion

Table 1 shows the results of the machine performance evaluation and Figure 9 shows (a) the partially dehulled seeds and (b) the kernels after dehulling. From Table 1, it can be seen that out of the total mass of 900 g of fluted pumpkin seeds loaded into the machine for performance evaluation, 402.86g of kernels, 80.1 g of partially dehulled seeds, 252g of shells, 34.6 g of escaped whole seeds (undehulled) and 115.84g of waste were obtained and the total time for dehulling all the 900g fed into the machine was 1150s (19.2mins). The lowest and highest times of operations were 57s and 91s respectively. The mean values of kernel, partially dehulled seed, seed coat, undehulled seeds, wasted seeds and time of operation obtained were 26.80g, 5.34g, 16.80g, 2.31g, 7.69g and 76.67 seconds respectively. The results above means that from 60 g of whole (undehulled) seeds used per run of the performance evaluation operation, 26.80 g, 5.34 g, 16.80 g, 2.31 g, 7.69 g of kernel, partially dehulled seed, seed coat, undehulled seeds, wasted seeds would be obtained respectively at mean time dehulling time of 76.67 seconds .

Table 1: Data obtained from dehulling machine performance evaluation

S/N	Kernel (g)	Partially dehulled seed (g)	Seed coat (g)	Undehulled seed(g)	Waste (g)	Time (s)
1	32.3	6.7	14.2	-	5.9	78
2	31.4	4.9	14-3	-	8.2	87
3	24.5	2.2	17.3	2.1	10.4	86
4	25.9	5.3	16.7	-	8.5	87
5	25.7	9.6	18.2	-	11.7	57
6	25.3	1.7	19.6	6.7	3.6	77
7	26.4	3.6	15.2	7.7	6.5	75
8	28.2	11.8	13.8	4.3	3.1	66
9	22.8	1.7	16.7	-	10.1	84
10	26.3	2.8	17.0	8.1	12.2	79
11	26.2	2.3	19.3	-	12.6	89
12	24.1	7.4	19.6	-	10.1	63
13	23.5	6.2	19.1	5.7	6.8	91
14	30.6	6.7	14.7	-	6.3	67
15	29.4	7.2	16.3	-	5.4	64
Total	**402.6**	**80.1**	**252**	**34.6**	**115.4**	**1150**
Mean	**26.80**	**5.34**	**16.80**	**2.31**	**7.69**	**76.67**

The machine's dehulling efficiency; the throughput capacity, percentage partially dehulled and percentage undehulled were evaluated to be 87.26%, 2.82 g/s 8.90% and 3.84% respectively. Alonge and Idung (2015) got 88% cracking efficiency and 916 seeds/h for bush mango seeds. Odewole and Ajibade (2015) got cracking efficiency of 96.65% and throughput capacity of 510 g/min for thevetia nut. Ologunagba, (2012) got cracking efficiency and throughput capacity of 75.11% and 426 kg/h for palm nut respectively. Oyebanji *et al*.,(2012) got cracking efficiency of 50.83% and 71.3% cracking efficiencies for centrifugal and impact palm nut cracker respectively. The closeness in values of performance indices in some cases could be due to the fact that some seeds have similar characteristics to fluted pumpkin seed used in this work in terms of their engineering properties; while wide difference in values could be due to method of cracking used, type and variety of seeds used, moisture contents of seeds during cracking, deficiency in design, fabrication and operation of cracking machine, and human factor in terms of lack of/inadequate technical know-how in operating properly designed and fabricated cracking machines for their intended purposes. Mohsenin, (1986) reported that the output of agricultural and processing machines depends on engineering properties of materials to be introduced into the machine. Also, results from Oyebanji *et al*., (2012) showed that methods of cracking in terms of principle of operation can cause differences in the outputs of machine. Furthermore, Ologunagba *et al*., (2010) got different values of machine performances in terms throughput capacity, separating efficiency and quality performance efficiency for palm nut and fibre separator when machine factors (tilt angle of machine) and crop factor (moisture content of palm nut) and moisture were used.

(a) (b)

Figure 9: (a) partially dehulled seed and (b) kernels (after dehulling)

4. Conclusions

A fluted pumpkin seed dehulling machine was developed and tested. The performance indices of the machine in terms of dehulling efficiency, throughput capacity, percentage partially dehulled and percentage undehulled were estimated to be 87.26%, 2.82g/s, 8.90% and 3.84% respectively. These values obtained from the performance indices are appreciable enough. Hence, the use of the machine will eliminate the drudgery attached to the traditional method and increase the recovery of kernels from the seed for oil extraction processes. It is therefore recommended that effect of different speeds of the machine and some crop factors on the performance indices of the machine should be done. Also, winnowing unit should be incorporated into future designs.

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