Design, Fabrication and Performance Evaluation of a Double-action Melon Seed Shelling Machine

Terhemba Iorpev, Rita O. Onah, Samuel B. Obetta

Abstract— Melon seeds contain high level of protein and oil which is relatively higher than the values in some oil-bearing seeds (cotton and groundnut). Its importance in daily meals and vegetable oil industry cannot be over emphasized. But the drudgery and poor rate of shelling associated with the manual shelling method is discouraging the industrial production of vegetable oil from melon seeds. So, a double-action shelling machine was designed, developed and tested in response to the challenge. The machine consists of a hopper, shelling unit, delivery chute, electric motor and a frame. The shelling of the seeds was effected by the sequential double-action of impact and shear forces generated by a rotating component at two separate regions. A performance evaluation of the machine was done at 750, 950 rpm and 18, 20, 22, 25% moisture content (db) in three replicates. Maximum shelling efficiency percentage of 85.29% and seed breakage percentage of 0.026% was obtained at 20% moisture content (db) and 950rpm operational speed. The seed breakage percentage was the lowest among the works cited. The capacity of the machine was 48.58 kg per hour at 950rpm operational speed. The analysis of variance (ANOVA) at P≤0.05 significance level showed that both the speed and moisture content levels have significant effect on the shelling efficiency while moisture content alone has significant effect on the seed breakage percentage. The machine is suitable and recommended for domestic and industrial use.

Index Terms— Design, Double-action, Melon seeds, Shelling machine

1 INTRODUCTION

Melon (Citrullus colocynthis L.) popularly known as 'Egusi' seed in Nigeria is an oil-seed crop that is widely cultivated and consumed in the tropics. The main cultivars of the crop are Bara and Serewe in Nigeria. Bara is characterised by large brown seeds, thick black edges, and a mean dimension of 16 x 9.5 mm. It is dominantly found in the Northern and western regions of Nigeria. Serewe seeds are smooth, light brown, unthicken whitish edge with 15 x 9 mm mean dimension. The cultivar is mainly found in the Eastern part of Nigeria [1].

Ajibola *et. Al.*, [2] shows that melon seeds consist of about 50% oil by weight, 37.4% protein, 2.6% fibre, 3.6% ash and 6.4% moisture. The oil content of melon seeds constitute 50% unsaturated fatty acids (35% Linolelic, and 15% Oleic) and 50% saturated fatty acid (Stearic and Palmitic acid) [1]. According to Norton [3], the average protein and oil content value of melon seeds are relatively higher than the values in some oil-bearing seeds such as cotton with 20.2% protein, 21.2% oil, and groundnut with 23.2% protein, and 44.8% oil. In [1], the presence of unsaturated fatty acids makes melon nutritionally desirable due to its hypocholestroleric (blood cholesterol lowering) effect. Research has shown that the consumption of melon seed and its products reduces the chances of developing terra-arterial or heart disease [2]. Melon has amino acid profile that compares favourably with that of soya beans and even white of egg [4]. The nutritional value of melon per 100g are: 7.6g carbohydrate, 0.4g dietary fibre, 0.2g fats, 0.6g protein, and 8mg vitamin C [1]. Shelled melon seeds are used for the production of soup, margarine, salad cream, livestock feeds, local pomade and soap [5].

The most challenging aspect of postharvest processing of melon is the mechanical shelling of seeds and separation of the kernels from the shells. The traditional method of shelling melon is tedious, time consuming and inefficient [6]. The drudgery and fatigue associated with melon shelling affects the market supply of shelled melon seeds thus, hindering the industrialization of melon oil production and other end products.

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2 LITERATURE REVIEW

In order to tackle the challenges associated with manual or traditional methods of shelling melon seeds, Fashina [7] developed a melon seed shelling machine that works by the action of sets of rollers' surfaces on the seed; Odigboh [8] designed and developed a melon shelling machine that operates on the principle of impact force from spinning disc; Fadamoro [9] designed and constructed another Sheller that works on the principle of friction between parallel, stationary disc and a rotating disc. Obienwe [10] also designed and constructed a melon machine that works on the principle of extrusion. Other researchers such as [11], [12], [13], [14], [15] also developed some melon seed shelling machines. According to [1], the performance efficiencies of the reported machines were a little above 30 percent.

In view of the prevailing challenge, the objectives of this work were to design and develop an efficient melon shelling machine with a double-action that would work on the principle of impact and shear forces powered by an electric motor; to determine its shelling efficiency, and seed breakage percentage of the machine.

3 MATERIALS AND METHODS

3.1 Materials

The materials used were selected based on strength, durability, suitability and availability without compromising the engineering codes and standards for fabrication of machines. Serewe specie of melon seed was used in the study. Mild steel metal sheets, bars and rods and fibre materials were used. Machines (Lathe, Electric drills, Arc welding machine) and tools (Chisel, Punch, Hammer, Steel rule, Tape) were used during fabrication.

3.2 Methods

Some physical, mechanical and gravimetric properties of melon seeds were studied and employed in the design and fabrication of the machine. Davis [16] reported some physical, gravimetric and frictional properties of melon seeds at 6.25% (d.b) as stated in table 1, 2 and 3 respectively which were found useful. The mean values of angle of repose, bulk density, porosity and seed dimension of melon seeds influenced the design configuration of the hopper, shelling mechanism and the delivery chute. The mass, true and bulk densities of the seeds were employed in shaft design and power requirement determination.

The moisture content of melon seed samples were determined by the oven drying method. The initial moisture content values of the seeds obtained were the base line that indicated the adequate amount of water that would be added to make the seeds suitable for shelling operation. Melon seeds samples at 18, 20 and 22 % moisture levels (d.b) were prepared by sprinkling adequate amount of water.

3.3 Design of Components

Standard engineering equations were used for the determination of the required parameters in the design such as machine's power requirement, torque generated, shaft diameter, electric motor size, belt size and pulley sizes.

Power Requirement

The power required to operate the machine at a maximum speed of 950 rpm was determined thus. According to [17],

Power, $P = T\omega$ (1)

Where T = Torque, ω = Angular velocity of the plate.

The values of Torque, T and angular velocity, ω were obtained by using equation 2 and 3.

Torque, $T = I\alpha$ (2)

Angular velocity, $\omega = 2\pi rpm/60$ (3)

Where $I = 0.118 kgm^2$, α = 20rps, rpm = 950r/m and
T = 14.83 Nm, ω = 99.43 rad/s,

Then

P = 1474.55 w or 1.98 Hp.

Hence, a 2 horse power electric motor was selected and used to power the machine.

Shaft design

TABLE 1
SOME PHYSICAL PROPERTIES OF MELON (CITRULLUS SPECIES) SEED AT 6.25%

Properties	Number of samples	Mean values
Length, mm	100	12.81
Width, mm	100	7.02
Thickness, mm	100	2.22
One thousand unit mass, g	50	94.0
Arithmetic mean diameter, mm	100	7.36
Geometric mean diameter, mm	100	5.84
Sphericity	100	0.47
Surface area, mm	50	134.64
Volume, mm	100	154.83

Source: Davis [16]

TABLE 2
SOME GRAVIMETRIC PROPERTIES OF MELON (CITRULLUS SPECIES) SEEDS AT 6.25% (D.B)

Properties	Mean values
Bulk density, $kg.m^{-3}$	405
True density, $kg.m^{-3}$	816.29
Porosity, %	53.7
Angle of repose	36

Source: Davis [16]

TABLE 3
SOME FRICTIONAL PROPERTIES OF MELON (CITRULLUS SPECIES) SEEDS AT 6.25% (D.B)

Properties	Mean values
Coefficient of static friction:	
Glass	0.35
Plywood	0.51
Galvanised metal	0.43

Source: Davis [16]

The required shaft diameter was determined by using the ASME code equation for solid shafts as in [18].

$$d^3 = 16/\pi S_s \sqrt{(k_b M_b)^2 + (k_t M_t)^2} \quad (4)$$

Where d = *diameter of shaft, m;* S_s = *Allowable shear stress, N/m²;* K_b = *Combined shock and fatigue factor applied to bending, Nm;* M_b = *Bending moment, Nm;* K_t = *Combined shock and fatigue factor applied to torsional moment, Nm;* M_t = *Torsional moment, Nm.*

For a vertical rotating shaft under gradual loading, based on ASME code, 1.5 and 1.0 were used for k_b and k_t respectively. 40MN/m² was used as allowable shear stress of the shaft while bending moment was considered negligible due to the orientation of the shaft, axial loading and position of the bearings along the shaft. By using equation 5, torsional moment of 20.105Nm was obtained.

$$M_t = 60P/2\pi N \quad (5)$$

Where, P = 1474.55 watt, N = 950 rpm, Torsional moment, M_t = 14.83Nm and substituting in equation 4, the minimum required shaft diameter was determined to be 12.36mm. However, putting the factor of safety into consideration, a shaft diameter of 22mm was used.

Pulley and Belt Design

A suitable pulley size and belt length was determined by using equation 6 [19] and equation 7 [20] respectively.

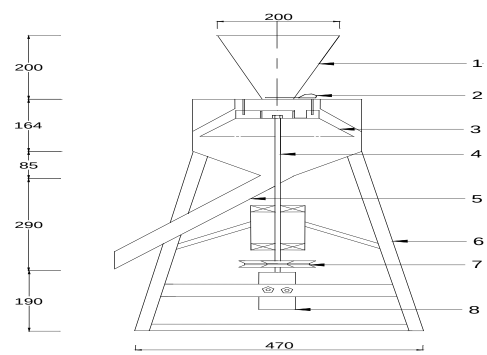
$$N_1 D_1 = N_2 D_2 \quad (6)$$

$$L = 2C + 1.57(D_2 + D_1) + (D_2 - D_1)/4C \quad (7)$$

Where N_1 = *speed of driven pulley, rpm;* N_2 = *speed of driving pulley, rpm;* D_1 = *Diameter of driven pulley, mm;* D_2 = *Diameter of driving pulley, mm; L = Length of belt, mm; C = Distance between driving and driven pulley, mm.*

3.4 Machine Description

The major components of the machine are: the hopper, shelling unit, delivery chute, electric motor and a frame as shown in figure 1. The hopper is a truncated cone of 200mm and 50mm diameter at the respective ends, and 200mm high. The angle of elevation (42 degrees) of the hopper facilitates particle flow by gravity. The feeding rate control regulates the quantity seeds fed per time. The shelling mechanism consists of padded metal beaters arranged at a spacing of 15mm apart on a plate of diameter, 140mm. The remaining area of the plate was lined with padded thin metal rods. The melon seeds were sequentially subjected to the double action of the machine inform of impact forces generated by the beaters and shear forces generated by the lined thin metal rods. The plate is mounted on a vertical shaft that rotates during operation. The plates collects the seeds from the hopper, impacts and shear them when rotating at a high speed. The shelled seeds are usually conveyed away by a centrifugal force. The shaft is restrained and hinged by two ball bearings. The delivery chute with a designed gradient of 45 degrees allowed the shelled seeds to flow out by gravity. An arrangement of two pulleys and a v-belt transmits the kinetic energy of the electric motor to the machine. The machine is powered by a single phase 2hp electric motor. Mild steel angle bar of 200mm X 200mm dimension was used for the construction of the frame.



Key: 1 = Hopper, 2 = Feeding rate control, 3 = Double-action Shelling plate, 4 = Transmission shaft, 5 = Delivery chute, 6 = frame, 7 = Pulleys, 8 = Electric motor.

Fig.1: Sectional view of melon shelling machine
Source: Iorpev [21]

When the electric motor is connected and switched on, the shelling plate is allowed to attain full operational speed before the feeding rate regulator is opened. The generated impact forces weaken and removes the whitish edge of the seeds at the top of the plate while the shear forces removes the cotyledon out of the shell at the side of the plate. The shelled particles are moved away from the shelling plate by the generated centrifugal force. The material finally flows out of the delivery chute by gravity.

4 PERFORMANCE EVALUATION

A two-factor factorial experimental designed in Completely Randomised Design (CRD) with three replications was adopted. The factors were machine speed at two levels (750 and 950 rpm) and moisture content at three levels (18, 20, 22 and 25% d.b). The seed samples were conditioned by using a procedure that involves sprinkling of water, allowing a soaking time of 6 hours and air drying for 10 minutes to evaporate the surface water [23]. The two levels of machine speed were enhanced by using pulleys with different suitable diameters.
The parameters evaluated were shelling efficiency, seed damage percentage, and machine capacity.
The following equations were used to determine the parameters as in [5].

Shelling efficiency, $\eta_s = 100(W_{su} + W_{sb})/W_t \quad (8)$

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Where W_{su} = *Weight of unbroken shelled seeds;* W_{sb} = *Weight of broken shelled seeds;* W_t = *Total number of seeds poured into the machine.*

Seed damage percentage = $100(W_{ub} + W_{sb})/W_t$ (9)

Where, W_{ub} = *Weight of unshelled but broken seeds;* W_{sb} = *Weight of shelled but broken seeds;* W_t = *Total number of seeds poured into the machine.*

Machine capacity, $C_m = M_S/T$ (10)

Where, M_s = *Mass of seed shelled, kg; T = Time taken for shelling operation, h.*

The data was analysed using SPSS version 16.0 statistical computer program. Mean values and the standard deviations were evaluated.

5 RESULTS AND DISCUSSION

Table 4 is a representation of the mean values of machine performance at some 750rpm and 950rpm machine speed, and 18, 20, 22% moisture content levels. The data in the table cannot reveal the effect of machine speed and moisture content on machine's performance clearly since the initial weight of melon among the various moisture levels are not kept constant except at same moisture levels. But table 4 only shows that the weight of shelled seeds, broken seeds and the time taken for machine operation increases as the machine's speed increases.

TABLE 4
MELON SEED SHELLING MACHINE PERFORMANCE TEST MEAN DATA

		Machine Speed							
	Total seed weight, g	**750rpm**				**950rpm**			
		Shelled weight, g	Broken weight, g	Weight of unshelled g	Time, s	Shelled weight, g	Broken weight, g	Weight of unshelled, g	Time, s
18	**165**	88.04 (0.25)	0.058 (0.01)	75.96 (0.04)	18 (0.10)	132.06 (0.38)	0.060 (0.01)	32.50 (0.56)	10 (0.09)
20	**190**	108.03 (0.33)	0.046 (0.00)	80.97 (0.28)	20 (0.11)	162.05 (0.92)	0.050 (0.01)	27.50 (0.07)	12 (0.10)
22	**200**	112.07 (0.30)	0.090 (0.01)	76.93 (0.67)	23 (0.15)	168.10 (0.35)	0.100 (0.01)	30.45 (0.55)	13 (0.08)
25	**225**	125.40 (0.56)	0.100 (0.01)	98.56 (0.67)	25 (0.12)	188.13 (0.29)	0.130 (0.01)	36.44 (0.86)	15 (0.13)

Note: Values in parentheses are the standard deviation values.

By statistical analysis, the highest shelling efficiency of 85.29% and seed breakage percentage of 0.026% was obtained at 20% moisture content (db) and 950rpm machine speed. The highest machine capacity of 48.58 kg per hour was obtained at that level.

The result of analysis of variance (ANOVA) in table 5 done on the shelling efficiency of the machine showed that at $P \leq 0.05$ levels of significance, both moisture content of the melon seeds and the speed of the machine have significant effect on the shelling efficiency of the machine. The efficiency increases with the speed and moisture content within the levels of factors considered. A similar trend was reported in [5] and [6].
The analysis of variance in table 6 shows that at $P \leq 0.05$ levels of significance, the moisture content of the seeds has significant effect on the seed breakage percentage while machine speed does not within the levels of factors considered. The 0.026% seed breakage percentage obtained was far lower than the 10% and 1% reported in [5] and [6] respectively. The variability in the shelling unit design and the operational speed could be responsible for the lower seed breakage percentage obtained.

TABLE 5
ANALYSIS OF VARIANCE (ANOVA) FOR SHELLING EFFICIENCY

Dependent Variable: Eff

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Model	40061.638[a]	5	8012.328	2.842E4	.000
M	21.163	3	7.054	25.018	.013
S	1540.125	1	1540.125	5.462E3	.000
Error	.846	3	.282		
Total	40062.484	8			

R Squared = 1.000 (Adjusted R Squared = 1.000

TABLE 6

ANALYSIS OF VARIANCE (ANOVA) F0R PERCENTAGE BREAKAGE

Dependent Variable: Percentage, %

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Model	.014[a]	5	.003	154.806	.001
M	.001	3	.000	16.086	.024
S	6.050E-5	1	6.050E-5	3.457	.160
Error	5.250E-5	3	1.750E-5		
Total	.014	8			

R Squared = .996 (Adjusted R Squared = .990)

7 CONCLUSION

A melon seed shelling machine was successfully designed, developed and tested. It can be concluded from the results obtained from the test and statistical analysis that, the speed of the machine and the moisture content of the seeds significantly affected the shelling efficiency of the machine. The shelling efficiency increased with the speed and moisture content of the seeds within the levels of factors considered. Seed breakage percentage of the machine was comparatively negligible and it is significantly affected by the moisture content of the seeds alone. However, the machine capacity could be better at a higher operational speed of the machine. Commercialisation of this machine will provide employment and simultaneously facilitate adequate supply of shelled melon seeds for domestic use and vegetable oil industries.

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