Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2018, 5(1):70-78**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Design and Performance Evaluation of Manually-Operated Melon Sheller

Nwadinobi Chibundo Princewill*[1], Mejeh Kingsley Ikechukwu[2]

[1]Department of Mechanical Engineering, Abia State University, Uturu, Abia State, Nigeria
[2]Department of Mechanical Engineering, Abia State Polytechnic, Aba, Abia State, Nigeria

Abstract A manually operated design of melon Sheller was developed and evaluated in this study. It consists of a hopper, the shelling chamber (consist of a rotating inner vanned drum and a fixed cylindrical ring), and an outlet unit. The developed machine recorded shelling performance accounting for an optimal throughput capacity of about 387kg/h, shelling efficiency of about 90% and seed damage value of 20% at seed moisture content of 18.37%. Results obtained during the performance evaluation indicates that the machine can efficiently shell melon seeds and that seed moisture contents have significant effect on the performance indicators than the drum speed of the shelling machine. Also, this melon shelling technology can effectively take care of the challenges posed by erratic power supply and the high cost of gasoline in developing countries, providing employment for small and medium scale farmers and food processors and at the same time make available quality melon seeds at low cost.

Keywords Melon, shelling, shelling efficiency, seed damage, moisture content

Introduction

The egusi melon known as *Colocynthis citrullus* L. is a member of the cucurbitaceae family and belongs to the Benicaseae tribe. The colocynthis is a small genus of about 4 to 5 species found in Africa, among which is the *C. citrullus* [1]. Melon is said to originate from Africa and Asia and areas where it is widely cultivated include the Caribbean, Indonesia and Africa [2]. This melon is also an important component of the traditional cropping system because it is usually interplanted with staple crops such as cassava, maize, sorghum, etc. According to Aguayo *et al* [3], egusi melon is the fourth most important crop in the world in relation to production (18 metric tons), after orange, banana and grape. Melon seed is also a good source of minerals, protein, vitamins, oil and energy in form of carbohydrates [4,5]. The seed contains 4.6g carbohydrates, 0.6 proteins, 33 mg vitamin C, 230 mg K, 0.6 g crude fiber, 16 mg P, 17 g Ca per 100 g edible seeds and unsaturated fatty acids [6,7]. The seeds are small, flat and partly oval in shape, containing cotyledons and it is an annual crop. They are rich in protein (40%) and edible oil (60%) [5]. Oils can be extracted for cooking purposes, the seeds can be ground into a powder and used as a soup thickener, and the ground seed is also used to prepare delicacies like cake. It is also processed into products such as livestock feed, while its oil is used in the production of soap and local pomade.

Furthermore, it is imperative to know that the processing of this melon in its raw form, diversifies its use. The processing of melon includes: fermentation, coring, washing, drying, shelling and oil extraction. Amongst these processes mentioned above, shelling has become a challenging process because it needs a relatively high utilization of human energy which is a major concern. It involves the removal of the outermost part (husk) from the melon kernel. Here, the seed (cotyledon) is separated from husk. Shelling of melon is therefore an important step towards the processing of melon to its finished product stage. Shelling can be done both manually and mechanically. Manual method is a traditional means of shelling, it does not encourage higher productivity, as it is time and energy consuming. Manual methods can be by picking and shelling or bagging and shelling. The inability to effectively shell melon to meet the needed requirement necessary for industrial uses has been a hindrance to its use for large-scale production [8]. To this end, this crude method is now being mechanized through the introduction of melon shelling equipment. This technique having been embraced in Nigeria in the quest for a satisfactory, affordable and effective means of melon shelling for small and medium scale farmers.

Different studies have been done on the design and development of melon shelling machines [7]. According to Kassim *et al* [9], attempts have been made on melon seed shelling by, [10-12]. Other works were done by [8, 13,14]. Based on the idea of every researcher, various designs and constructions of a mechanized melon Sheller exist. While some are based on their shelling mechanism, others are based on their source of power, and can therefore be classified as electrically powered, fuel-driven or manually driven melon shelling machines.

However, with the prevalence of the erratic power supply and rising cost of petroleum products in Nigeria and most developing nations, it is imperative to consider the power source for this equipment. This is also in consideration of cost effectiveness, simplicity, friendliness, hygiene and technologically feasible system. Therefore, this work is centered on the design and performance evaluation of a manually operated melon Sheller that can effectively shell melon varieties found in Nigeria. This is without damaging the cotyledon by breakage or crushing and also to be fabricated at an affordable price using locally available materials.

Materials and Methods

Machine Description and Fabrication Procedure

The fabrication of this machine was carried out in the Mechanical Engineering Workshop, School of Engineering Technology, Abia State Polytechnic, Aba. The manufacturing processes adopted in the fabrication of this machine include Cutting, Turning, Welding and Painting. The melon shelling machine consists of three sections, the hopper, the shelling chamber which is made up of the Inner shelling drum and Outer drum and the shaft, the gear system and Base as shown in fig 1. The Inner drum is a cylindrical device which revolves inside the outer drum thereby producing the collision needed for shelling, its surface is lined with fins inclined at an angle of 30 degrees to the surface. It has a detachable shaft fixed at the centre, which provides drive for the drum through the drive shaft. Lastly is the chute, where the mixture of melon seed and shell are discharged from.

In the fabrication, mild steel metal sheet was marked out and cut with the aid of scriber, meter rule, compass and metal sheet sheerer thereafter it was folded, then welded with an arc welding machine. The hopper consists of four welded mild steel metal sheets slanting towards the smaller opening. The larger opening at the upper part is for introducing the melon seeds into the Sheller while the smaller lower opening in the hopper, connects it to the shelling chamber. It is made of mild steel plate of 1.5 mm thickness. It has an upper opening, measures 300 mm by 300 mm and the lower end 56 mm by 56 mm. This is followed by the shelling chamber consisting of the fixed shelling drum (concave), the shelling vanes and the rotating shelling disc (convex). The outer (fixed) drum houses the inner drum and have small rods of 2 mm thickness (stoppers) lined on its inner surface at specified gaps. The fixed cylindrical ring has diameter of 231 mm. This enhances the collision which is needed for shelling. The Shelling disc is lined with flat metal vanes at an inclination. The rotating drum has diameter of 225 mm, with vanes inclined at an angle of 30˚ round it. Cylinder-concave clearance of 5 mm was adopted [15]. The outer drum also has inlet and outlet holes/port located along its circumference from where the melon are fed into the shelling chamber and also discharges. It has a cover at one side which is fastened, for easy servicing of the shelling chamber. Two bearing are attached at the centre ends to make for smooth drive of the inner drum. In the bid to achieve the desired speed required for shelling in the manually operated melon Sheller, a gear and pinion system was introduced. A handle is attached to the large spur gear which serves as the driver gear where effort is inputted. The small gear (pinion) is fixed to the drive shaft connecting the inner rotating drum. Therefore as the two gears mesh, the driver gear transmits rotational speed to the pinion based on their gear ratio. Also part of the fabrication is a thick flat metallic sheet that caries all the parts of the machine known as the base.

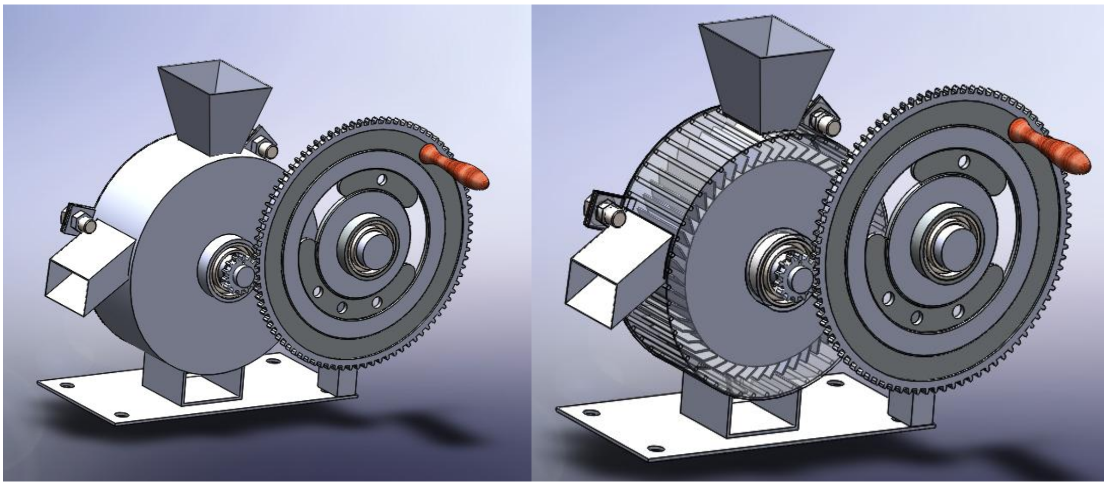

Figure 1: Detailed drawing of the manually operated melon Sheller

Principle of Operation

This Machine, has these component parts which are: Hopper, Shelling Unit, Discharge Unit, Power Source Unit. The working principle of the melon Sheller is hinged on the principle of energy absorption by a seed due to impact (collision) between the seed and a stationary wall which results in the cracking and separation of the seed from its coat. The melon Sheller contains a rotating inner drum moving at a certain speed received from the gear drive sufficient enough to generate a force whose magnitude is high enough to shell the melon seeds. The unshelled melon seeds that are free from dirt, are fed consistently through the hopper into the shelling chamber where the seeds move between a rotating inner drum and a fixed cylindrical ring that encloses the drum. The unshelled seeds which absorb initial velocity coming from the vanes of the rotating drum which rotates anticlockwise. This is to improve the collision of the unshelled seeds with the rough body of the shelling unit (lined with rod weldments), then causing the breakage of the shell and the removal of cotyledon from the coat before getting down the outlet point. These labelled parts are as presented in fig. 2.

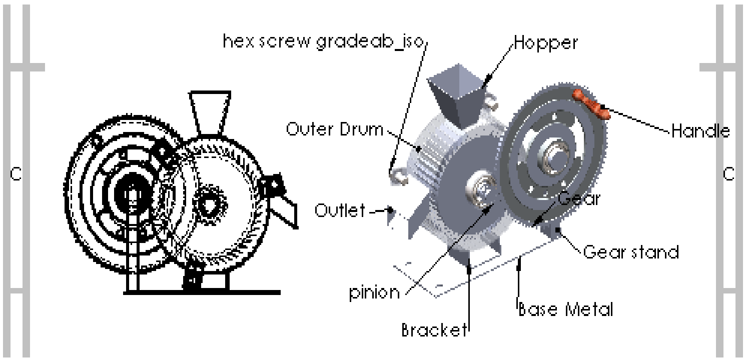

Figure 2: Labelled parts of the manual melon Sheller

Design Analysis of Manual Melon Shelling Machine

The manual melon shelling machine was designed and developed based on the following considerations:

Power required for shelling by the machine: Total Power required is obtained using the equation as given by Akintunde *et al* [16],

$$P_{Total} = P_{Inner\ drum} + P_{Shaft} + P_{Shelling}\ (where\ P_{Shelling}\ is\ negligible)$$

So, $P_{Total} = P_{Inner\ drum} + P_{Shaft}$ (1)

Since Shaft and Inner drum are fixed together;

$P_{Total} = P_{Inner\ drum\ +Shaft}$ (2)

According to Khurmi and Gupta [17], power transmitted (in watts) by the shaft, is given as

$P_{Inner\ drum\ +Shaft} = T\omega = T \times \frac{2\pi N}{60}$ (3)

Where, T= Torque transmitted in N-m, N= Speed of the shaft system in r.p.m and ω = angular velocity

Torque developed by shelling shaft: The Torque developed by the shelling shaft was obtainable using equation as given:

$$Torque\ trinsmitted\ by\ shelling\ shaft(T) = \omega r \quad (4)$$

where ω = angular velocity and r = radius of shelling disc.

Design of Shaft: A shaft is the rotating machine element which transmits power from one place to another [17]. The shaft of the melon Sheller, rotates the shelling disc and carry combined load of bending moment and torque; therefore the design of the shaft was calculated from the formula given by Adekunle [8],

$$\tau = \frac{16}{\pi d^3}\sqrt{M^2 + T^2} \quad (5)$$

where, T = Twisting moment/Torque (Nm), M = bending moment of shaft, τ = Torsional shear stress (N/m^2) = 42 MPa [17], d = Diameter of shaft (m). With M = 62.8 Mpa, T = 7.5 Nm, τ = 108.33 Mpa, shaft diameter d was calculated as 16.2 mm.

Selection of bearing: Ball rolling contact bearing of standard designation 201 was selected for the machine. This selection was based on the type of load the bearing will support when at rest and during operation and also based on the diameter of the shaft. The designation 201 signifies small series bearing with bore (inside diameter of 12mm) to apply [17].

Gear Design: Considering the manually operated unit, which incorporates the gear transmission system. Spur gear was used which consisted of a gear system made from cast iron rotates at ratio 14:1 with the pitch diameter of the pinion and crank being 504mm and 36mm respectively. Calculating the dynamic load (W_D) on the gear tooth by using Buckingham equation, i.e.:

$$W_D = W_T + W_I = W_T + \frac{21v(bC + W_T)}{21v + \sqrt{bC + W_T}} \quad (6)$$

$$W_T = \frac{2M_t}{D} \quad (7)$$

$$b = KP_c \quad (8)$$

$$P_c = \frac{\pi D}{T} \quad (9)$$

where

W_D = Total dynamic load (N), W_T = Steady load due to transmitted torque (N), W_I = Increment load due to dynamic action (N),v = Pitch line velocity (m/s),b = Face width of gears (mm), and C = A deformation or dynamic factor in N/mm (depends on the tooth form, material and the degree of accuracy with which the tooth was cut), M_t is torque on weaker gear, D is Diameter of the pitch circle,4 ≤ K, T = Number of teeth on the wheel, P_c is Circular pitch.

The permissible working stress, according to the Barth formula,

$$\sigma_w = \sigma_o \times C_v \quad (10)$$

where

σ_o= Allowable static stress (196 Mpa-Cast steel, heat treated), and Cv= Velocity factor.

The values of the velocity factor (Cv) for ordinary cut gears operating at velocities up to 12.5 m/s which was applied in this work is given as

$$C_v = \left[\frac{3}{3+v}\right] \quad (11)$$

Analysis of the weight capacities of the shelling unit: The volume capacity of the shelling unit, depends on the volume of the hopper. The weight capacity was thus derived from the weight-density-volume relationship (equ. 12).

$$W = \rho v g \quad (12)$$

Where ρ= density, v = volume and g = acceleration due to gravity (9.8m/s^2).

Considering 25% head space for the shelling unit, the effective weight capacity of the shelling unit (W_1) was determined as 43.8N, from equ. (13).

$$W_1 = 2.45H\rho_m\left(L_tW_t + L_bW_b + \sqrt{L_tW_tL_bW_b}\right) \quad (13)$$

Where ρ_m ($600kg/m^3$) is the bulk density of unshelled melon at moisture content between 9.53-24.08% [18]; L_t (0.30m), L_b (0.056m), constitute the respective lengths of the top aperture of the hopper, base aperture of the hopper; W_t(0.30m), W_b (0.056m), are the respective widths of the hopper's top aperture, hopper's base aperture; H (0.17m), is the height of the hopper.

Performance Analysis Procedure

The melon seeds used was procured from Umungasi market in Aba, Abia state, Nigeria. The unshelled melon seeds used was weighed (25g each), sprinkled with water and partially dried with natural air for 15 minutes, so that the skin coat became slightly softened and the cotyledon detached from the shell, thus making shelling more efficient [8]. The melon shelling machine was fed with 25g sample of the variety followed by the shelling operation using the manual operation. ASAE standard S.352 was used in calculating moisture content (ASAE, 1982). Five (5) runs of experiment was conducted. At the end of each experiment, the seeds were carefully collected from the outlets and divided into: number of seeds shelled unbroken (N_1), broken shelled (N_2), partially shelled (N_3), unshelled (N_4), broken unshelled (N_5) and crushed (N_6) and sorted separately in the respective shelling operation and subsequently weighed and noted. From the acquired data, these shelling performance parameters: Percentage seed damage (S_d), shelling efficiency (η_{eff}) and throughput capacity (TP) were calculated using equations (14-16) respectively.

$$Percentage\ seed\ damage(S_d) = \frac{Total\ melon\ broken + crushed}{Total\ melon\ fed\ into\ the\ machine} = \frac{N_2+N_5+N_6}{N} \quad (14)$$

$$Machine\ shelling\ efficiency\left(\eta_{eff}\right) = \frac{Total\ melon\ shelled\ by\ machine}{Total\ melon\ fed\ into\ the\ machine} = \frac{N_1+N_2}{N} \quad (15)$$

$$Throughput\ capacity(\text{TP}) = \frac{Total\ melon\ fed\ into\ the\ machine}{Time\ taken\ to\ complete\ operation} = \frac{M_f}{T} \quad (16)$$

Furthermore as part of its performance evaluation, a comparative test was also conducted on two other melon Shellers of same design specifications but operated with different power sources. This is aimed at determining the effects of drum speed and moisture content on the shelling performances. The impeller speed and five (5) different moisture content levels were investigated to know whether they have significant effect on the shelling and breakage of the melon seeds during shelling.

Results and Discussion

The data gotten from the moisture content experimental results obtained are as presented in table 1 which shows the moisture content of the five (5) samples which were utilized for the comparative appraisal.

Table 1: Summary of Moisture Content Experimental Procedure

S/N	Soaking Time (min)	Sample Initial Mass (g)	Sample Final Mass (g)	Moisture Content (%)
1	5	25	26.87	7.46
2	8	25	27.56	10.24
3	12	25	28.48	13.92
4	16	25	29.59	18.37
5	20	25	30.36	21.42

Table 2 presented the results of the shelling product output of the developed manual melon shelling machine. Considering the average value for the various grades of product output, the average percentage of shelled unbroken and shelled broken melon seeds for all operations were 56.8% and 30% respectively. Further analyses of the result revealed that the quantity of partially shelled melon seed in percentage value of 7.2%. Also, the percentage of unshelled melon, unshelled broken melon and that of crushed melon are 3.4%, 2.6 and 0% respectively.

Table 2: Shelling Values for Manual Operation

Moisture Content (%)	Initial mass (g)	shelled unbroken (m_1) (g)	broken shelled (m_2) (g)	partially shelled (m_3) (g)	unshelled (m_4) (g)	broken unshelled (m_5) (g)	crushed (m_6) (g)	Time taken (hr)	Total (g)
7.46	25	10.45	9.68	1.2	0.84	0.68	0	0.06	22.85
10.24	25	12.37	8.42	1.03	0.69	0.72	0	0.06	23.23
13.92	25	14.29	6.68	0.92	0.64	0.62	0	0.06	23.15
18.37	25	16.95	4.04	0.9	0.71	0.65	0	0.06	23.25
21.42	25	15.83	4.85	1.02	0.85	0.57	0	0.06	23.12

In addition, from the experimental data obtained in table 3, it was discovered that moisture content of the sample specimen played an important role in melon shelling performance. Where by the higher the moisture content, the better the shelling performance when the maximum retention capacity have not been reached. However, at maximum water retention capacity of the melon, lower shelling performance is expected. Here, the breakages were attributed low moisture content than speed variation. The trend of results showed minimal effect of speed on the shelling performance. Also, higher speeds reduced shelling time, irrespective of the seed moisture contents.

Table 3: Shelling Values for Shelling Operation with electric motor

Speed (rpm)	Moisture Content (%)	Initial mass (g)	shelled unbroken (m_1) (g)	broken shelled (m_2) (g)	partially shelled (m_3) (g)	unshelled (m_4) (g)	broken unshelled (m_5) (g)	crushed (m_6) (g)	Time taken (hr)	Total (g)
850	7.46	25	9.01	10.86	1.4	1.03	0.71	0	0.04	23.01
	10.24	25	11.82	8.05	1.2	0.76	0.84	0	0.04	22.67
	13.92	25	12.53	7.68	1.08	0.84	0.71	0	0.04	22.84
	18.37	25	12.95	7.04	1.32	1.07	0.68	0	0.04	23.06
	21.42	25	13.52	6.32	1.1	1.01	0.62	0	0.04	22.57
1000	7.46	25	8.54	10.28	1.86	1.42	0.83	0	0.03	22.93
	10.24	25	10.74	8.36	1.25	1.4	0.72	0	0.03	22.47
	13.92	25	13.52	6.85	1.04	0.73	0.8	0	0.03	22.94
	18.37	25	13.68	6.73	1.21	0.82	0.73	0	0.03	23.17
	21.42	25	14.51	6.17	0.94	0.73	0.58	0	0.03	22.93
1200	7.46	25	8.52	11.08	1.53	0.92	0.74	0	0.025	22.79
	10.24	25	12.65	7.69	1.02	0.8	0.71	0	0.025	22.87
	13.92	25	14.52	6.04	1.15	0.65	0.74	0	0.025	23.10
	18.37	25	16.83	3.57	0.94	0.82	0.68	0	0.025	22.84
	21.42	25	16.29	4.01	1.24	0.72	0.64	0	0.025	22.90

Tables 4, 5 and 6 show the shelling performance characteristics results at different moisture contents and shelling speeds using three power sources (manual operated, electric motor and gasoline engine). The performance indicators which are percentage seed damage, shelling efficiency and throughput capacity were obtained at varied shelling speeds and moisture contents.

Table 4: Performance indicators at drum speed of 850 rpm

Percentage seed damage (%) at 850 rpm			Shelling efficiency (%) at 850 rpm			Throughput capacity (kg/h) at 850 rpm		
Fuel generator	**Electric motor**	**Manual operation**	**Fuel generator**	**Electric motor**	**Manual operation**	**Fuel generator**	**Electric motor**	**Manual operation**
0.5285	0.5028	0.4534	0.8791	0.8635	0.881	570.5	575.25	380.833
0.3778	0.3921	0.3935	0.8662	0.8765	0.895	558.5	566.75	387.167
0.355	0.3673	0.3153	0.8847	0.8849	0.9058	572.5	571	385.833
0.3342	0.3348	0.2017	0.8804	0.8669	0.9028	568.5	576.5	387.5
0.3166	0.3075	0.2344	0.8891	0.879	0.8945	561.5	564.25	385.333

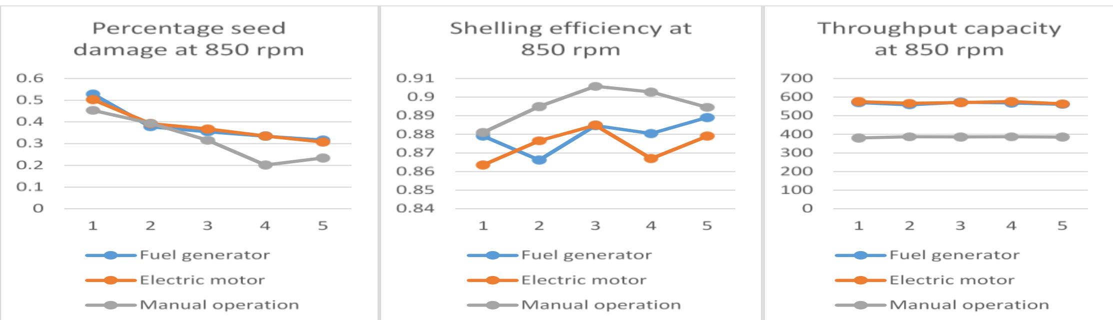

Figure 3: Comparative presentation of performance indicators at drum speed of 850 rpm

The percentage seed damage was evaluated using equation 14. The highest seed damage was obtained at 1200 rpm and 7.46% moisture content for the three power sources studied and the least value of 0.2031% obtained at same speed and 18.37% moisture content. Also, an increase in seed damage was generally observed to occur with decrease in moisture content. This is a resultant effect of increased dryness of the seed and it has to do with the subjection of the seeds to stresses exceeding their maximum resistance resulting from increase in speed.
The shelling efficiency of the machine was evaluated using equation 15. The effect of shelling speed and moisture on shelling efficiency is presented also in figures 3, 4 and 5 respectively for the three power sources. This was observed to increase with an increase in seed moisture content and drum speed ranging between 82 to 91% across the power sources used in the comparative evaluation.

Table 5: Performance indicators at drum speed of 1000 rpm

Percentage seed damage (%) at 1000 rpm			**Shelling efficiency (%) at 1000 rpm**			**Throughput capacity (kg/h) at 1000 rpm**		
Fuel generator	**Electric motor**	**Manual operation**	**Fuel generator**	**Electric motor**	**Manual operation**	**Fuel generator**	**Electric motor**	**Manual operation**
0.4528	0.4845	0.4534	0.8159	0.8208	0.881	744.333	764.333	380.833
0.4269	0.4041	0.3935	0.8803	0.85	0.895	718.333	749	387.167
0.3338	0.3335	0.3153	0.8763	0.888	0.9058	776	764.667	385.833
0.3112	0.322	0.2017	0.8817	0.8809	0.9028	763.667	772.333	387.5
0.289	0.2944	0.2344	0.8778	0.9019	0.8945	769.333	764.333	385.333

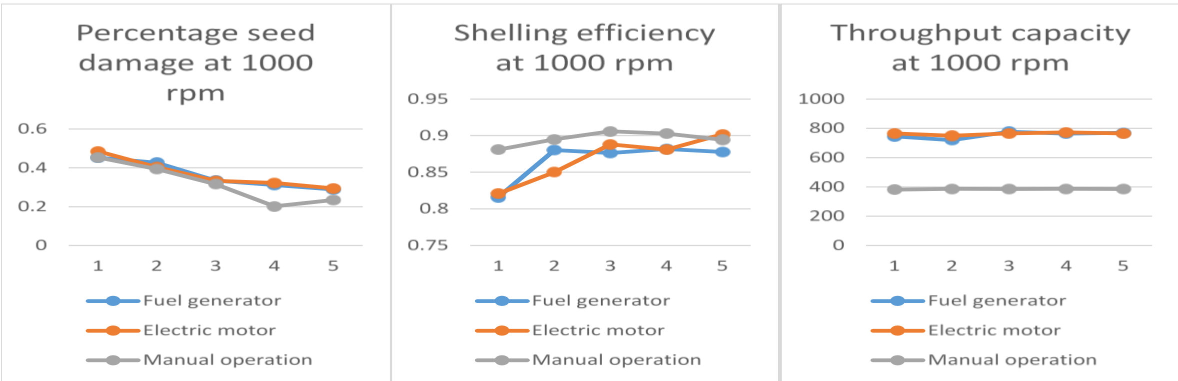

Figure 4: Comparative presentation of performance indicators at drum speed of 1000 rpm

Furthermore, equations 16 was applied for the throughput capacity calculation. From the results obtained across the power sources utilized, the throughput increased with increase in speed. This is ascribed to the fact that throughput being a function of input mass and process time, at increased speed, processing time is reduced since the input quantity is same for each speed and experimental run.

Table 6: Performance indicators at drum speed of 1200 rpm

Percentage seed damage (%) at 1200 rpm			**Shelling efficiency (%) at 1200 rpm**			**Throughput capacity (kg/h) at 1200 rpm**		
Fuel generator	**Electric motor**	**Manual operation**	**Fuel generator**	**Electric motor**	**Manual operation**	**Fuel generator**	**Electric motor**	**Manual operation**
0.5336	0.5186	0.4534	0.8616	0.86	0.881	922	911.6	380.833
0.3591	0.3673	0.3935	0.8927	0.8894	0.895	921.2	914.8	387.167
0.2543	0.2935	0.3153	0.8885	0.89	0.9058	893.6	924	385.833
0.1625	0.1861	0.2017	0.8905	0.8932	0.9028	920.8	913.6	387.5
0.2376	0.2031	0.2344	0.9054	0.8865	0.8945	917.6	916	385.333

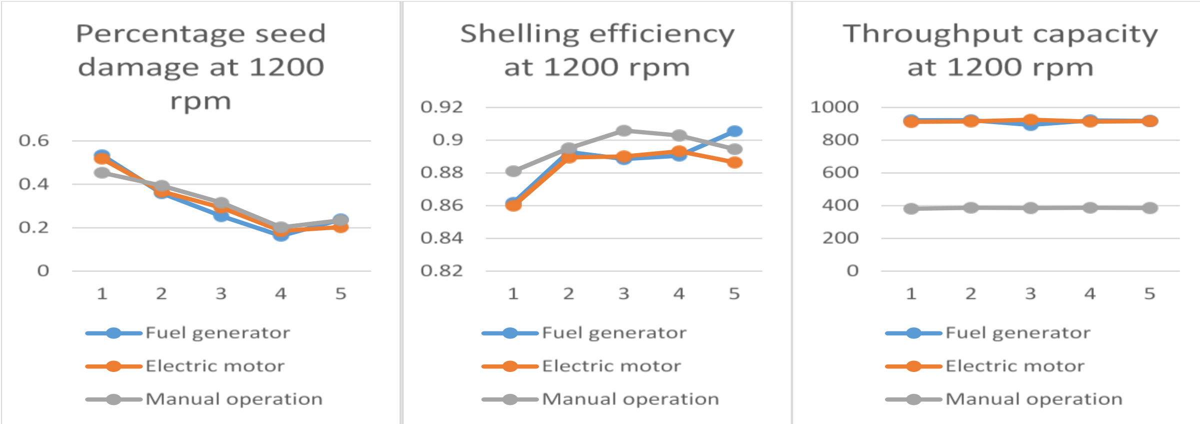

Figure 5: Comparative presentation of performance indicators at drum speed of 1200 rpm

Conclusion

A manually operated melon Sheller design was developed and evaluated in this study. The shelling performance of the developed machine accounted for an optimal throughput capacity of about387kg/h, shelling efficiency of about 90% and seed damage value of 20% at seed moisture content of 18.37%.Results obtained showed that the machine can effectively shell melon seeds and that seed moisture contents and the speed of the shelling machine affected the performance indicators. Moreover, the shelling efficiency increases with an increase in moisture content below the maximum retention capacity of the melon with shelling speed showing insignificant effect at optimal moisture content level. The machine is user friendly, requires no skilled labour, no fossil fuel product and also the incessant power interruptions prevalent in developing countries such as Nigeria, and does not affect its use. Also, this melon shelling technology could effectively address the need of rural dwellers as well as small and medium scale farmers in developing countries providing employment and at the same time make available quality melon seeds at low cost.

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