

Development of a Moringa Oleifera Seed Shelling Machine

Muritala O. Iyanda^{1,a}, Elijah A. Alhassan^{2,b*}, Christian O. Osueke^{3,c}
and Clinton E. Okonkwo^{2,d}

¹Department of Agricultural and Biosystems Engineering, University of Ilorin, Ilorin, Nigeria.

²Department of Agricultural and Biosystems Engineering, Landmark University, Omu Aran, Nigeria.

³Christian O. Osueke, Department of Mechanical Engineering, Landmark University, Omu Aran, Nigeria.

^aiyandamo@yahoo.com, ^balhassan.elijah@lmu.edu.ng, ^cosueke.christian@lmu.edu.ng,
^dokonkwo.emeka@lmu.edu.ng

Corresponding Author's E-mail address: alhassan.elijah@lmu.edu.ng

Keywords: moringa seeds, rural farmers, performance evaluation, machine speed, feedrate.

Abstract. The rising awareness of the importance of moringa seeds has geared interest in its mass production. A major step in making the seed available for its vast usage is shelling. Most rural farmers of moringa seed use the traditional methods of shelling. These methods are tedious, time consuming with attendance low outputs that produce unhygienic products. The need to develop appropriate machines and equipment for processing of moringa seeds become necessary. This work developed a moringa seed shelling machine using available local materials. The development of the shelling machine was based on engineering mechanics of impact and shearing forces. The machine consists of a hopper, shelling unit, shafts, cleaning unit, sieve, discharge unit, power transmission unit and frame. The machine was evaluated based on variation in speed and feedrate to obtain the shelling efficiency, throughput capacity and percentage seed damage at 14% (d.b) moisture content powered by a 0.75 kW electric motor. The results obtained show that the machine has the highest shelling efficiency of 72.72% at 60 g/min feedrate with a throughput capacity of 8.31 kg/hr and the minimum percentage seed breakage of 2.22%. Machine speed of 250 rpm favoured the smooth operation and performance of the machine. The machine is very useful for rural people, farmers and small scale industries for post-harvest processing of moringa seeds since its cost and operational principle is within their technical know-how and capability.

1. Introduction

Moringa oleifera is of the *Moringaceae* family and moringa genus is the best known and commonly found species. A fast-growing drought-resistant tree, native to the southern foothills of the Himalayas of northwestern India, is now widely cultivated in the tropical and subtropical areas [1-2]. *Moringa oleifera* is commonly called horseradish tree because of the taste of its roots or drumstick tree based on the shape of its pods in English, but it has different names in many localities [1].

Moringa is a multi-purpose tree as its importance cuts across many facets of human endeavours namely food for human and animals [3, 4], water treatment and purification [5, 6], medicine [3], industrial use like lubricant, perfumery and in soap production [4], agriculture for erosion control, live fence, windbreak, shade, stake, and as a bee plant [3], biodiesel production [7, 8], for economic and foreign exchange earnings [4, 6]. Despite the numerous economic and industrial benefits of moringa seeds, shelling is mostly carried out manually by pounding in a mortar using a pestle or beating the dried seeds in sacks using clubs with the seed coat and kernel separated by winnowing [9]. This is a tedious exercise and the product obtained from these methods is very low, market demand and quality are compromised because of kernel breakage and contaminations.

Shelling is the process by which dry shell (coat) breaks and detached from the kernel. This activity produces clean, whole kernels free of cracks because whole kernels have better economic values than broken ones [10]. For such a crop, whose importance is growing and gaining attention rapidly,

with attendant drudgery in manual shelling, development of needed shelling machine will be of great benefits to moringa growers and processors. Review of literatures show different types of shelling machines developed for many edible and non-edible oil seeds such as groundnut [11], jatropha fruit [12], melon [13, 14], Bambara ground nut [15], chironji nut [16], cashew [17], moringa seed [1,2], sal seed [18] etc. Although the development of moringa seed processing machines have generated significant interest in recent time, the need to revolutionize the industrial utilization of moringa seeds processing machines by making quality and high-performance machines at cost within the reach of peasant farmers become eminent. This work, therefore, designed, fabricated and evaluated a motorized moringa seed shelling machine in terms of shelling efficiency, throughput capacity and seed breakage index. Factors that affect moringa seed shelling were also examined and established for the development of the machine.

2. Materials and Methodology

2.1. Materials

In the design of agricultural machines, it is important to establish relevant physical and mechanical properties of crops to be handled. Properties such as breadth, mass, hardness, moisture content, angle of repose and bulk density were established for moringa seed with the force required to break a seed found to be about 2.7 N [19]. Selected raw materials for fabrication were based on strength, stability, durability, cost, and availability [12]. These construction materials are mild steel, shaft, angle iron, galvanized sheet, sieve, bearing, pulley, belt, disc, flange, and electric motor. Moringa seeds were purchased from the University of Ilorin Moringa Research Farm, Ilorin, Nigeria (located on longitude 4.54° E and latitude 8.50° N). It was manually cleaned and sorted to remove the bad seeds from the samples. The exploded and orthographic views of the fabricated moringa seed shelling machine are shown in Figures 1 and 2.

2.2. Design Considerations

Engineering mechanics relating to forces of impact and shearing guide the design of the machine. Many factors were considered to produce an efficient machine. The following factors were of utmost importance for the development of the moringa sheller:

1. Simplicity in design, construction, and operation
2. Easy of operation and low maintenance
3. Use of locally available materials
4. Safety, size, and weight to ease transportation and enhance safe operation
5. The strength of materials and durability
6. Power requirement
7. Cost of construction

Significant physical and mechanical properties of moringa seeds were used for the machine design. Flow characteristics and angle of repose of the seeds dictate the design of the hopper [20].

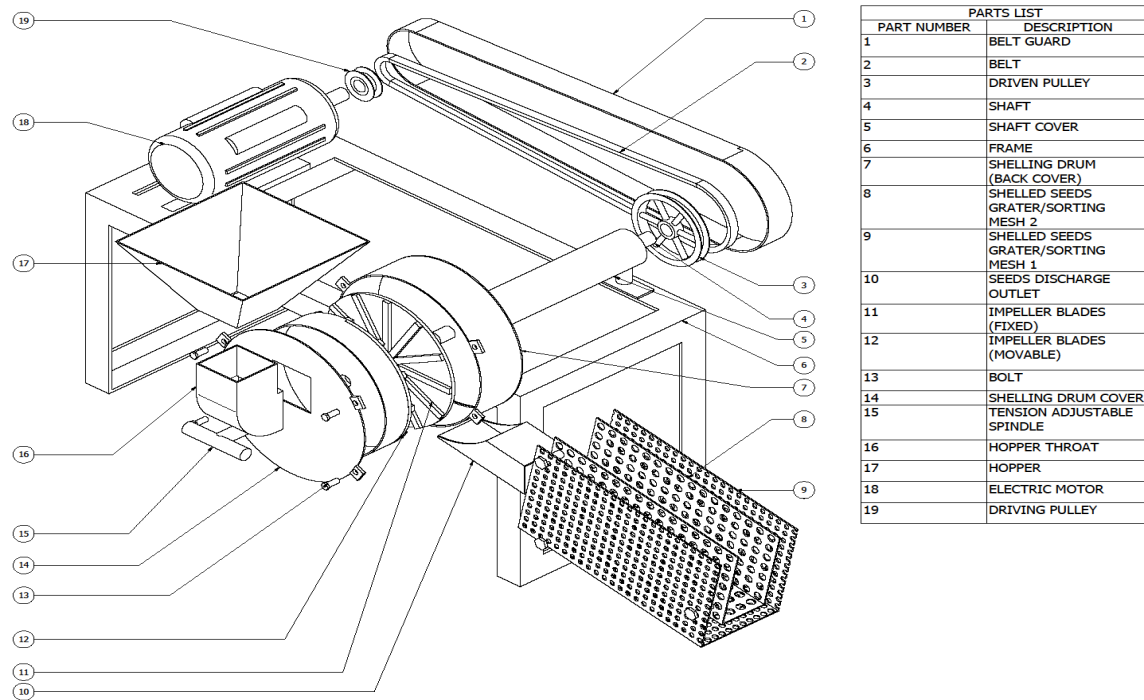


Figure 1 Moringa shelling machine exploded view of the various component parts

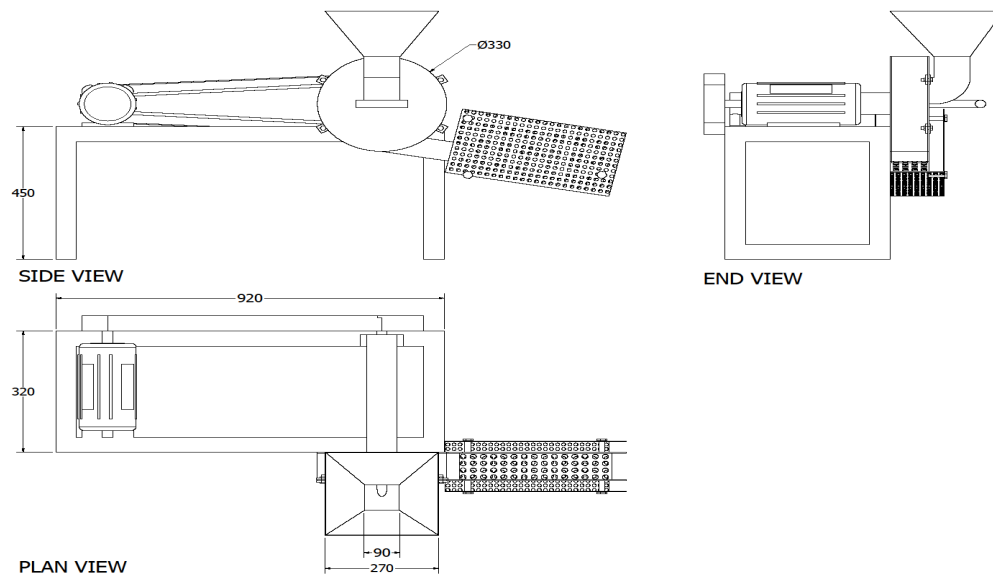


Figure 2 Moringa shelling machine orthographic view with dimensions in mm

2.3 Machine Component Parts Design Analysis

Basic consideration was given to belt drive tension and length, shaft and pulley diameter, breaking force and power requirement. Principal dimensions of the seeds play a major role in the design of sieves and also helps in the grading of materials [21]. Hardness, deformation at hardness and fracturability of the seed were some of the mechanical properties used for the design of blades, number, length and thickness of blades, and shaft diameter [18]. The determination of the various dimensions for the different components design of the moringa seed sheller was achieved using Equations 1-10 [14, 20, 22 – 30].

2.3.1 Hopper design

The hopper capacity of the machine was calculated using Equations 1, 2, 3, and 4 for trapezoidal shaped hopper.

$$\text{Total volume } (V) = V_A + V_B \quad (1)$$

$$V_A = \frac{h_1}{3} (A_1 + A_2 + (A_1 \times A_2)^{0.5}) \quad (2)$$

$$V_B = h_2^3 \quad (3)$$

where;

V_A = volume of the square tapered section of hopper, (m^3)

V_B = volume of the cubical bottom section of the hopper, (m^3)

h_1 = height of the square tapered section of hopper, (m)

h_2 = height of the cubical bottom section of the hopper, (m)

A_1 = area at top of the tapered section, (m^2)

A_2 = area at bottom of the tapered section, (m^2)

$$V_A = \frac{0.3}{3} (0.073 + 0.0081 + (0.073 \times 0.0081)^{0.5}) = 0.011 \text{ m}^3$$

$$V_B = (0.08)^3 = 5.12 \times 10^{-4} \text{ m}^3$$

$$V = 0.011 + 5.12 \times 10^{-4} = 0.01151 \text{ m}^3$$

$$\text{Density} = \frac{\text{mass}}{\text{Volume}} \quad (4)$$

The average bulk density as stated by [20] was 662 kg/m³

$$\text{Hopper capacity} = 662 \times 0.01151 = 7.62 \text{ kg}$$

2.3.2 Breaking force determination (F_b)

Each seed was observed to be shelled with a force of 2.7 N. Impact of force per serrated impact line = 18 seeds x 2.7 N = 48.6 N,

18 segments impact lines = 18 x 48.6 N

$$\therefore F_b = 874.80 \text{ N (at maximum loading condition)}$$

2.3.3 Determination of belt drive tensions

If the mass of disc are assumed to be negligible, the impact force per cycle is 874.80 N is taken to be tight side belt tension in the V-belt drive.

$$T_1 = 874.80 \text{ N (tight side tension)}$$

But in V-belt drive for maximum power transmission, the ratio of T_1 to T_2 is normally taken

$$\frac{T_1}{T_2} = 5 \quad (5)$$

$$T_2 = 174.96 \text{ N (slack side tension)}$$

2.3.4 Determination of power requirement

$$\text{Power } (P) = \frac{2\pi NT}{60} \quad (6)$$

where

N = Driver pulley (300 to 650), rpm

N = 300 rpm (minimum was selected),

T = Torque of driven pulley on the shaft

$$P = 1869 \text{ W}$$

In practice, $\frac{1}{3}$ of the seed used is assumed to be fed each time

$$P_n = 623 \text{ W (nominal power required)}$$

$$\therefore \text{Design power } P_d = \text{Nominal power } (P_n) \times \text{service factor } (f_s)$$

f_s = Assumed value of 1.2

$$P_d = 747.6 \text{ W} = 0.75 \text{ kW}$$

2.3.5 Determination of pulley diameter

$$\text{From } v = \frac{\pi DN}{60} \quad (7)$$

where,

N = Driver pulley speed, rpm; D= Diameter of the driver pulley, mm

Also from the relation

$$P = VT_E \quad (8)$$

Where,

P = Power required by the machine; V = Speed in m/s

T_E = Effective belt tension (N) = $T_1 - T_2$ ($T_1 = 874.80$ N and $T_2 = 174.96$ N)

$T_E = 699.54$ N

$$V = \frac{P}{T_E} = \frac{1869}{699.54} = 2.67 \text{ m/s}$$

When N= 250 rpm

$$D = \frac{V60}{\pi N} = \frac{2.67 \times 60}{3.142 \times 250} = 203.94 \text{ mm (select 200mm)}$$

When N= 300 rpm

$$D = \frac{V60}{\pi N} = \frac{2.67 \times 60}{3.142 \times 300} = 170 \text{ mm}$$

When N= 350 rpm

$$D = \frac{V60}{\pi N} = \frac{2.67 \times 60}{3.142 \times 350} = 145.67 \text{ mm (select 150mm)}$$

2.3.6 Determination of shaft diameter:

If the bending stress is repeatedly reversed and the torsional stress is nearly uniform. Also, if the shaft is to be designed on the basis of strength such that combine twisting (torsion) and bending is experienced by the driven shaft in operation, then the ASME equation base on maximum shear stress theory was used to determine the diameter of the shaft.

$$d^3 = \frac{16}{\pi \tau_{max}} \sqrt{(K_b M_B)^2 + (K_t M_t)^2} \quad (9)$$

Where

d = shaft diameter required.

τ_{max} = maximum allowable shear stress on the shaft = 42 N/mm²

K_b = Combined shock and fatigue factor for bending = 1.5

K_t = Combine shock and fatigue factor for torsion = 1.0

M_b = beading moment of belt Drive on shaft = 55.74Nm

M_t = torsional moment on the shaft = 59.48 Nm

$d \approx 19.05$ mm

A shaft diameter of 25 mm of service factor 1.3 was chosen due to the toughness of undehulled moringa seeds and the volume of moringa seeds in the shelling unit per time.

2.3.7 Determination of Belt length (L)

Belt length for open belt drive was obtained from Equation 10

$$L = 2c + 1.571 (D_2 - D_1) + \frac{(D_2 - D_1)^2}{4C} \quad (10)$$

Where;

L= required belt length,

C = pulleys center distance = 0.75 m

D_2 = Driven pulley diamater = 170 mm = 0.17 m

D_1 = Driver pulley diamater obtained = 35.40 mm (Pulley of 40 mm was used)

$L \approx 1844.6$ mm = 1.84 m (V-belt, A-type was used)

2.4 Machine Description

The basic components of the machine are the hopper, the disc with sieve, the shelling and cleaning chamber, the belt guard and the frame. The hopper was made of mild steel having an opening protruding directly into the shelling chamber. The shelling chamber consists of a stationary disc, rotational disc, and flange, powered by an electric motor. The shelling disc was made of galvanized steel; the rotating disc was welded to a flange with a rotation made possible because of flange attachment to the shaft. The whole machine was supported on a frame of angle iron.

2.4.1. Component parts of the machine

Hopper unit: A rectangular structure in which the material to be shelled is regulated and channeled into the shelling chamber. It was made of 1.5 mm mild steel metal sheet of dimension 310 x 320 mm, tapered towards the shelling mechanism for easy flow of the materials by gravity.

Shelling unit: It is made up of sharp projections called the flange (beater) mounted on the shaft, on the two-disc (rotational and stationary disc). The stationary (fixed) disc is 24.5 mm, while the rotational is mounted on the disc drum connected to the shaft that transmits pulley for shelling.

Frame: It supports the entire machine and made of angle iron of dimension 300 x 300 x 2 mm. It provides stability and strength to the machine.

Sieve unit: Made from a galvanized sheet of 1.5 mm thickness. The sieve was perforated based on the shape and size of the moringa seeds to provide efficient separation of the seed from the chaff after shelling.

Sieve outlet: The sieve outlet was made from mild steel sheet of 2 mm thickness. This was folded in the shape that allows the shelled grains to be collected after shelling.

2.5. Principle of Operation of the Machine

Shelling was achieved by the shelling bar on the flange (drum) rubbing against the stationary disc. The working principle of the machine is based on the energy absorbed by the seeds resulting from impact (collision) between the seeds and the stationary disc and shearing which result in cracking to remove the seeds coat. Clean, unshelled moringa seeds were fed into the machine through the hopper which opens directly into the shelling chamber. The unshelled seeds were supplied with initial velocity by the impeller disc bent at angle 45°. It rotates anticlockwise in order to enhance collision in the shelling chamber. This resulted in breakage of seed coat and removal of the kernel from the seeds. Chaffs were thrown out of the impellers through outlet chute designed at incline angle to facilitate cleaning under gravity. The machine was powered by a 0.75 kW electric motor connected through belt and pulley arrangement.

2.6. Experimental Procedures

Preliminary test at no load was carried out to observe and establish the working condition of the machine in preparation for the experiment. Three levels of speed (250, 300 and 350 rpm) and feedrate (50, 60, and 70 g/min) were used and time taken for the operation was determined using a digital stopwatch. The experimental factors (feedrate and machine speed) were replicated three times with the moisture content (14% d.b.) and the discs clearance kept constant.

2.7 Performance Evaluation of Moringa Seed Shelling Machine

Moringa seeds were used to evaluate the performance of the moringa seed shelling machine developed. Sample moisture content and concave clearance were kept constant, with feedrate and machine speed as the independent variables to obtain the dependent variables of shelling efficiency, throughput capacity and percentage seed damage (Equations 11-13) using the methods described by [31].

$$\text{Shelling Efficiency (\%)} = \frac{Q_s - Q_d}{Q_t} \times 100 \quad (11)$$

$$\text{Percentage Seed Damage (\%)} = \frac{Q_d}{Q_u + Q_d} \times 100 \quad (12)$$

$$\text{Throughput Capacity (kg/h)} = \frac{Q_s}{T_m} \quad (13)$$

where

Q_s : Mass of shelled moringa oleifera seed (kg)

Q_d : Mass of damaged moringa oleifera seed (kg)

Q_t : Mass of shelled and unshelled moringa oleifera seed (kg)

Q_u : Mass of undamaged moringa oleifera seed (kg)

T_m : Time of shelling operation (h).

3. Results and Discussion

The shelled, broken and unshelled seeds were collected and weighed separately. The values obtained were used for the computation of the dependent variables. The output obtained for the shelling efficiency, percentage seed damage and throughput capacity were as presented in Figures 3, 4, and 5.

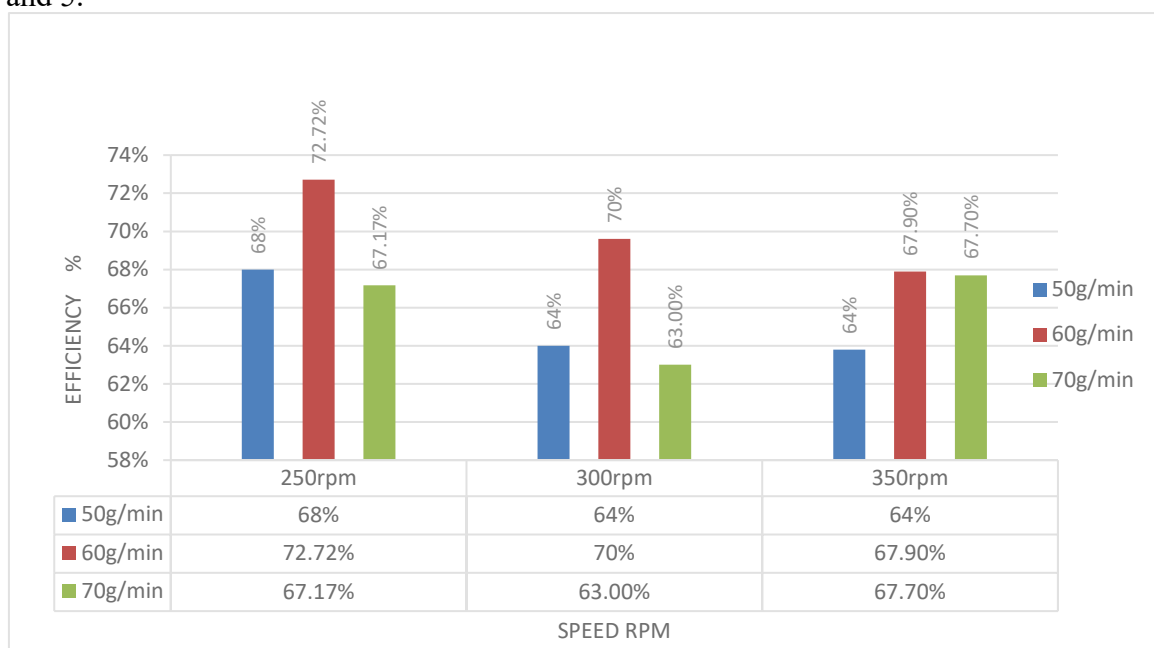


Figure 3 Shelling efficiency of the machine at various speed and feedrate

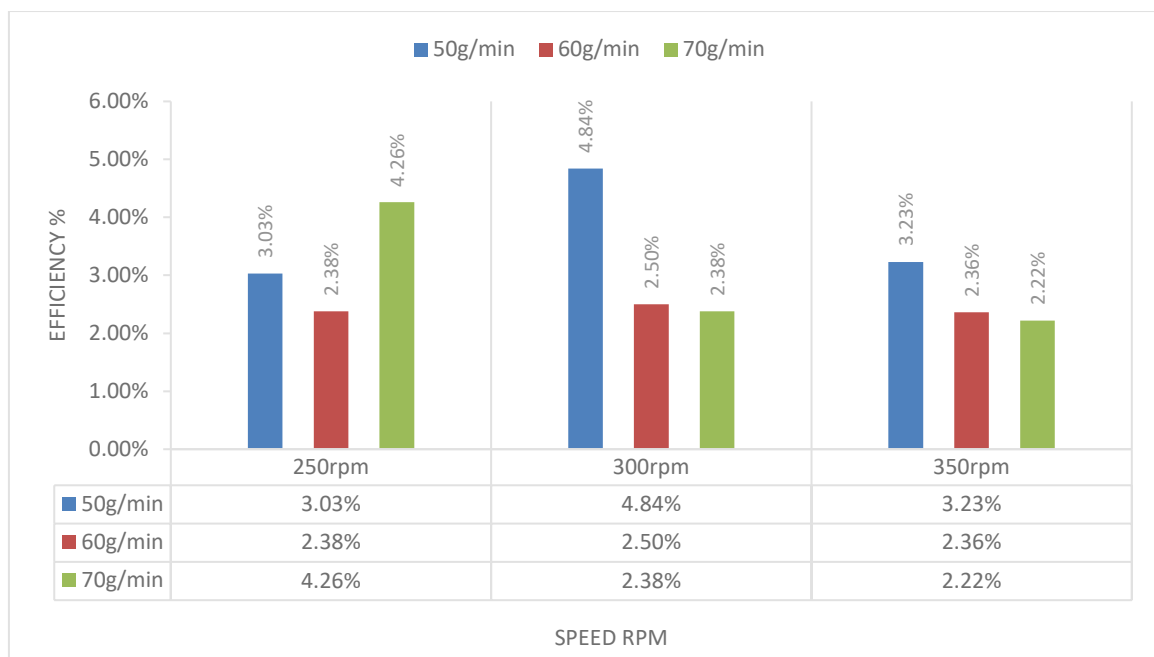


Figure 4 Seeds broken index of the evaluated machine at various speed and feedrate

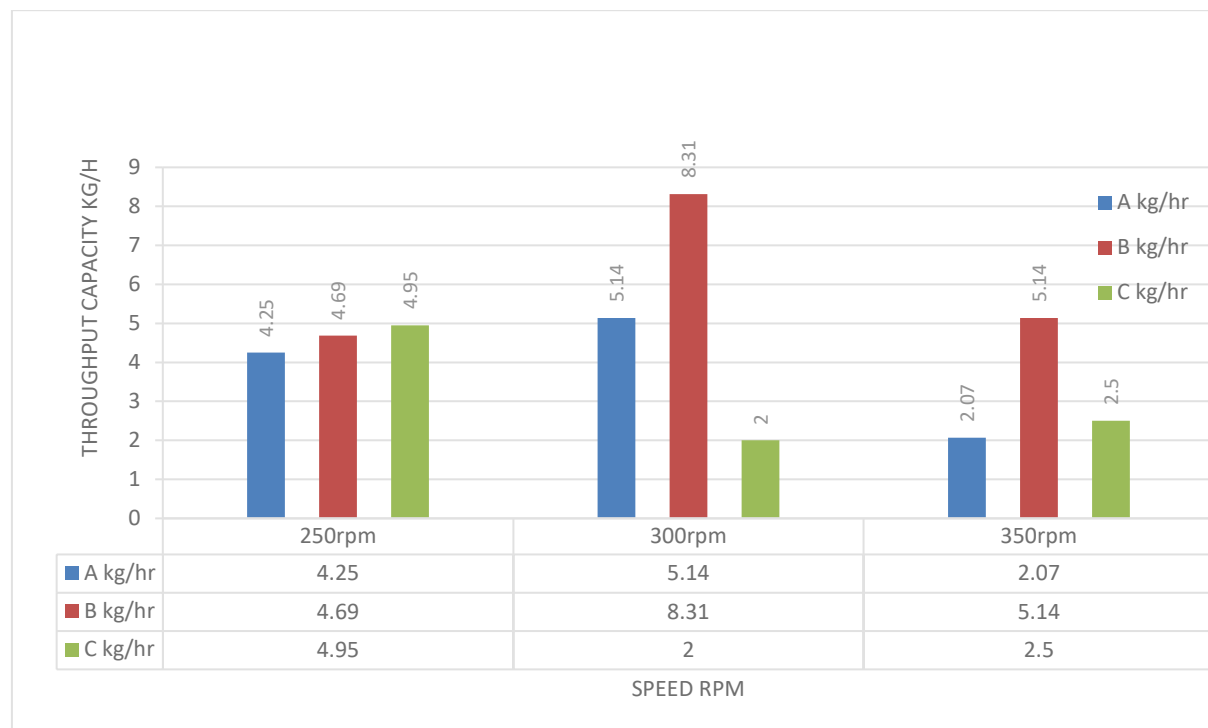


Figure 5 Throughput capacity of the machine at various speed and feedrate

The results obtained revealed the influence of feedrate and speed of operation on the performance of the moringa seed shelling machine. It is necessary to establish the appropriate operating parameters for the machine in order to obtain efficient operation, performance, and quality products. At low rpm, the interaction between the seeds and the shelling mechanism is enhanced. This resulted in the highest percentage of seed detached from the seeds coat. Most desirable results output were obtained at 60 g/min feedrate.

The highest shelling efficiency obtained was 72.72% at 250 rpm, 60 g/min feedrate and the least shelling efficiency was 62.90% at 350 rpm, 70 g/min feedrate. The high operating speed generate more energy from shaft rotation that produce a turbulent agitation of the samples without commensurate detachment of the coat from the seeds. When the machine was operated at 300 rpm, 50 g/min feedrate, the percentage of seed damaged was the highest (4.84%) because the residence time for rubbing action was more while the least was 2.22% at 350 rpm, 70 g/min feedrate. This was due to less of the seeds being shelled though there was turbulent agitation as a result of the high operational speed and also the large quantity of the seeds (70 g/min) being handled. Both the highest and the lowest throughput capacity were obtained at 300 rpm but at different feedrates, 8.31 kg/hr at 60 g/min and 2.00 kg/hr at 70 g/min. The trend of the throughput capacity was fairly constant for machine speed at 250 rpm with an increasing order from feedrate 50 g/min (4.25 kg/hr) to 70 g/min (4.95 kg/hr). Machine speeds of 300 and 350 rpm follow a similar pattern of increasing order from 50 g/min, peaking at 60 g/min and then decreasing from 60 g/min to 70 g/min.

The machine shelling efficiency tends to increase from 50-60 g/min feedrate but decreases from 60-70 g/min. The reverse was observed for the breakage efficiency as it decrease from 50-60 g/min feedrate and increase for 60-70 g/min feedrate. For efficient operation of the machine, it is recommended that operating speed of 250 rpm at 60 g/min feedrate should be used for quality product and maximum output. The outputs obtained from the machine compete favourably with what was obtained by [1, 2]. The machine can be of great importance for moringa seed farmers and processors.

4. Conclusion

To ease the stress involved in making moringa seed available for its vast applications, a moringa sheller was developed using locally available materials. Rural farmers were the target of the

machine, hence its operations, repair and maintenance were made simple. Results show that feedrate and machine operating speed has an effect on the performance of the moringa seed shelling machine at constant moisture content and discs clearance. Operating the machine at 250 rpm gave the highest efficiency of 72.72% at 60 g/min feedrate and 2.36% breakage efficiency, a moisture content of 14% (d.b.). Machine performance was found to be satisfactory, but incorporating mechanical blower into the machine will enhance proper cleaning. There is also the need to redesign the discharge outlet for free flow of the seeds during operation and varying the moisture content and discs clearance.

Acknowledgment

We sincerely acknowledge the critical observations, comments, and corrections of esteemed reviewers whose inputs improved the execution of this work considerably. We also thank the editor and the anonymous reviewers for their valuable comments.

References

- [1] O. Fadele, A. Aremu, Design, construction and performance evaluation of a Moringa *oleifera* seed shelling machine. *Engineering in Agriculture Environment and Food*, (2016) 1–7.
- [2] P.P. Ikubanni, C.A. Komolafe, O.O. Agboola, C.O. Osueke, Moringa seed dehulling machine: A new conceptual design. *Journal of Production Engineering*, 20(2) (2017) 73-78. <http://doi.org/10.24867/JPE-2017-02-073>.
- [3] C. H. Bosch, Moringa stenopetala (Baker f.) Cufod. In: Grubben, G.J.H. & Denton, O.A. (Editors). PROTA 2: Vegetables/Légumes. [CD-Rom]. PROTA, Wageningen, Netherlands. 2004.
- [4] J. Schneemann, Moringa (stenopelata) production and use for water purification in Ethiopia. Fair and sustainable advisory services. 2011. www.fairandsustainable.nl
- [5] N. Foidl, H.P.S. Makkar., K. Becker, The potential of Moringa *oleifera* for agricultural and industrial uses. What development potential for Moringa products? Oct 20th – November 2nd 2001, dar Es Salaam. (2001) 20 pp.
- [6] T.V. Heijden, F. Hendriks, P. Hoek, G. Lysen, R. Meijers, Moringa *oleifera* for a healthy future. Water purification using Moringa *oleifera* seeds. RSG Pantarijn, Wageningen. (2011) 23 pp.
- [7] U. Rashid, F. Anwar, M. Ashraf, M. Saleem, S. Yusup, Application of Response Surface Methodology for optimizing transesterification of Moringa *oleifera* oil: biodiesel production. *Energy Conversion Management*, 52 (2011) 3034- 3042.
- [8] O.A. Adejumo, 2012. Effect of Moisture Content on some Physical Properties of Moringa *oleifera* Seeds. *IOSR Journal of Agricultural and Veterinary Science*, 8 (1) (2012) 13-26.
- [9] S.C. Kumar, R.C. Pradhan, P. Ghosh, S.S. Rana, S. Mishra, Shore arobusta (Dipterocarpaceae) seed and its oil as food. *International Journal of Food Sciences and Nutrition*, 4 (2015) 228–233.
- [10] ITDG, Cashew Nut Processing, ITDG Practical Answers to Poverty: Technical Brief, Intermediate Technology Development Group, Rugby. 2002.
- [11] A. S. Raghtate, C. Handa, Design and fabrication of groundnut sheller machine. *International Journal of Innovative Research in Science Technology*, 1 (2015) 38–45.
- [12] R.C. Pradhan, S.N. Naik, N. Bhatnagar, V.K. Vijay, Design, development and testing of hand-operated decorticator for jatropha fruit. *Appl. Energy*, 87(2010a) 762- 768.
- [13] A. S. Adekunle, I. O. Ohijeagbon, H. D. Olusegun, Development and performance evaluation of manually and motorized operated melon shelling machine using impact technique. *Journal of Engineering Science and Technology Review*, 2 (2009) 12-17.
- [14] S.S. Sobowale, J.A. Adebisi, O.A. Adebo, Design and performance evaluation of a melon sheller. *Journal of Food Process Engineering*, 2015. doi:10.1111/jfpe.12259

-
- [15] F. Oluwole, A. Abdulrahim, M. Oumarou, Development and performance evaluation of impact bambara groundnut sheller. *International Agrophysics*, 21(2007) 269.
 - [16] J. Kumar, P. Vengaiah, P. Srivastava, P. Bhowmick, Chironji nut (Buchananialanzan) processing, present practices and scope. *Indian Journal of Traditional Knowledge*, 11 (2012) 202–204.
 - [17] S.J. Ojolo, O. Damisa, J.I. Orisaleye, C. Ogbonnaya, Design and development of cashew nut shelling machine. *Journal of Engineering, Design, and Technology*, 8 (2) (2010) 146 – 157
 - [18] C. S. Kumar, R. C., Pradhan, S. Mishra, Fabrication, performance evaluation and optimization of Sal (*Shorea robusta*) seed decorticator. *J. of Food Process Engineering*, (2016) doi 10.1111/jfpe.12468.
 - [19] A. L. Balogun, F. Uthman, A.A. Ayantola Design, development and testing of moringa shelling machine, proposed paper at the 6th National Conference, School of Applied Science, Offa Kwara State, 2014.
 - [20] E.A. Ajav, O. A. Fakayode, Physical properties of moringa (*moringa oleifera*) seeds in relation to an oil expeller design. *Agrosearch*, 13(1) (2013) 115-129, <http://dx.doi.org/10.4314/agrosh.v13i1.11>
 - [21] R.C. Pradhan, V. Meda, S.N. Naik, L. Tabil, Physical properties of Canadian grown flax seed in relation to its processing. *International Journal of Food Properties*, 13 (2010b) 732–743.
 - [22] V. Kumar, D. Rajak, R. Kumar, V. Kumar, P.D. Sharma, Design and development of low-cost makhana grading and roasting machine. *International Journal of Food Engineering*, 2014 10(3): 357–366, doi 10.1515/ijfe-2013-0056
 - [23] R.S. Khurmi, J. K. Gupta, A Textbook of Machine Design. Multicoloured Edition. Eurasia Publishing House Ltd., 7361, Ram Nagar, New Delhi-110055. 2006.
 - [24] R.L. Norton, Machine Design, An Integrated Approach. 3rd Edition Pearson –Prentice Hall, New Jersey, USA, 2006, pp 503-569
 - [25] A.K. Srivastava, E.G. Carroll, P.R. Roger, R.B. Dennis, Mechanical Power Transmission. Chapter Four In: Engineering Principles of Agricultural Machine. ASABE, St. Joseph, Michigan, 2006 pp. 65-90.
 - [26] C.E. Okonkwo, A. Olaniran, J.O. Ojediran, T.A. Olayanju, F. Ajao, A.S. Alake, Design, development, and evaluation of locust bean seed dehuller. *Journal Food Process Engineering*, 2018;e12963. <https://doi.org/10.1111/jfpe.12963>
 - [27] J.O. Ojediran, C. E. Okonkwo, A.A. Okunola, A. S. Alake, Development of a motorized rice de-stoning machine. *AgricEngInt: CIGR*, 20(4) (2018) 202-209 <http://www.cigrjournal.org>
 - [28] E. A. Alhassan, A. D. Adewumi, B. Okpodjah, Development of a self-propelled multi-crop two rows precision planter: A new design concept for the metering mechanism. *International Journal of Mechanical Engineering and Technology (IJMET)*, 9(10) (2018) 349–358. <http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=9&IType=10>
 - [29] R. L. Mott, Machine Element in Mechanical Design. 4th Edition Pearson–Prentice Hall, New Jersey, USA 2004, pp 530-574.
 - [30] J. N. Nwakire, B. O. Uguishiwu, C. G. Ohagwu, Design, Construction and Performance Analysis of a Maize Shelling Machine for Rural Dwellers. *Nigerian Journal of Technology*, 30 (2) (2011) 49-54
 - [31] J.N. Maduako, M. Mathias, I. Vanke, Testing of an engine powered groundnut shelling machine. *Journal of Agricultural Engineering and Technology*, 14 (2006).