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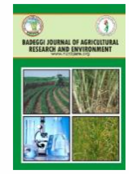

Review Article

Development of *Moringa Oliefera* Seed Decorticating Machine

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Abstract
In order to solve the boredom involved in *Moringa oleifera* decorticating operation which is one of the major factors militating against large scale production , processing and the use of this important oil crop, a mechanically operated moringa seed decorticating machine was developed. The machine consists of three major units, the decorticating unit which cracks and dislodges the inner shell from the nut, the blower unit which is incorporated to facilitate easy and proper cleaning and separation of the seeds from the chaffs and the winnowing unit which further clean and separate the seed from the chaffs. The machine is operated by a 2hp electric motor. Performance tests were carried out using three levels of moisture contents of moringa seed (7%, 10% and 13%) and at three levels of cylinder speeds (230 rpm, 330 rpm and 430 rpm). Each one replicated three times, gave the average decorticating and cleaning efficiencies of 88.00 % and 86.40 %. The machine had average seed losses of 2.29 % and undecorticated seeds were 16 %. The average kernel recovery efficiency was found to be 97.7 %. The ANOVA results show that the moisture contents and speeds have significant effect on both the decorticating and cleaning efficiencies of the machine at ($P < 0.05$), though the interaction between the factors (speeds and moisture contents) do not show any significant effect on decorticating and cleaning efficiencies at ($P < 0.05$). The developed machine could reduce the drudgery involved in manual decortication of 5 kg/day and saves about 70 % operating time.

Keywords: *Moringaoliefera* seed, Decortication, Separation, Kernel recovery

Introduction

Moringa oliefera also known as a Miracle tree belongs to a monogenetic family, the Moringaceae. It has a host of other country specific vernacular names, an indication of the significance of the tree around the world (Sharma *et al*., 2006). It is believed to have originated from south Asia, where it grows in the Himalayan foothills from North Eastern Pakistan to Northwest Bengal, India (Sharma *et al*.., 2011). It has been introduced and be grown in other parts of India, Pakistan, Afghanistan, Bangladesh, Sri Lankan, Southeast Asia, West Asia, the Arabian Peninsula, East and West Africa, including Nigeria, Southern Florida, throughout the West Indies, and from Mexico to Peru, Paraguay and Brazil. In Puerto Rica, it is grown chiefly as an ornamental and in fence rows and hedges and has become naturalized along roadsides on the coastal plains and lower foot hills. The rapid growing tree was utilized by the ancient Romans, Greeks and Egyptians. It is now widely cultivated and has become naturalized in many location in the tropics (Fahey, 2005). Fahey (2005) and Fuglie (1999) also observed that the fast-growing tree is grown for human food, medicine, dye, fodder and water clarification. It has an impressive range of medicinal uses with high nutritional value. In addition to its compelling water purifying powers and high nutritional value all parts of Moringa tree are edible and have long been consumed by humans. According to Fahey (2005) other uses of

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Moringa include: animal forage (leaves and treated seed-cake), biogas (from leaves), domestic dye (wood), fencing (living trees), fertilizer (seed cake), foliar nutrient (Juice expressed from the leaves), gum (from tree trunk), honey (flower nectar), medicine (all plant parts), ornamental plantings, bio-pesticide (soil incorporation of leaves to prevent seedling damping off), pulp (wood), rope (bark), tanning for tanning hide (bark and gum), water purification (Powdered seeds). The species are drought resistant. Olajide (2000) considered Moringa as an oil seed containing between 35 – 40 % oil called Ben oil. Oil seeds are important components of tropical agriculture as they provide readily available and highly nutritious elements for human and animal foods. The unit operations involved in this oilseed processing are decortications, seed cleaning, size reduction, rolling, conditioning and oil extraction. The seed cake remaining after extraction is reported to be very high in crude protein (nearly 60 %) making it a desirable source of animal fodder. However, the result of good oil extraction is dependent on the quality of decortications of this seed. Decortication is the most difficult operation in the processing of *moringa oliefera* seed to obtain the oil from the kernel, in Nigeria the method of decorticating Moringa seed is still manual which is achieved through pounding using pestle and mortar. This method is not only inefficient but also very laborious and the output is low about 0.005 tons/day (Anantachar *etal*., 1997) resulting in delay in handling large volumes of moringa harvest and subsequently leading to losses. Plate I shows Moringa tree and its product. It is therefore necessary to develop a machine for this purpose. The developed machine will improve the production output and the efficiency of the processing operation.

Materials and Methods

Machine Construction Materials: The materials were selected based on strength, availability and durability. The following materials were selected i) mild steel iron sheet gauge16, ii) mild steel iron rod of Φ2 mm, iii) mild steel angle iron 50 × 50 × 6 mm, iv) Mild steel shafts Φ30 mm and Φ25 mm, v) sieves Φ9 mm and Φ11 mm, vi) ball bearings (P205 and P206), vii) bolt and nuts (17 mm and 13 mm) and viii) green paint (1 tin). The following design considerations were taken into account in order to select the dimension and sizes of the machine components.

Engineering Properties of Seed

For the purpose of this design the following engineering properties of moringa seeds were considered; the length, equatorial diameter (width) and breadth (thickness). Knowledge of these dimensions is useful in determining aperture sizes in the design of seed handling equipment. Again, these dimensions, together with other parameters like the geometric mean diameter, arithmetic mean diameter, aspect ratio and sphericity describe the size and shape of the seed which influence its behaviour. For example, the flowability characteristic of the seed is influenced by the sphericity, such that movement of non-spherical seeds under gravity is mostly slow and on their flat surfaces (Francis, 2012). Angle of repose was employed in the design of hopper, drag coefficient and terminal velocity were used in the determination of sizes and aperture of fan blower.

Portability: The design considered the possibility of easy transportation of the machine whenever necessary. In view of this, the design allows for dismantling of the various basic units of the machine.

Design Theories and Calculations

Design of hopper capacity

The shape, location and dimension of the hopper were selected to ensure mass outflow of moringa seeds from the hopper to and to minimize arcing and funnelling. The dynamic angle of repose of moringa was determined, taking into consideration factors affecting the determination of angle of repose. This angle was found to be $50.12\,°$. The machine throughput capacity of 480 kg/day was selected. The dimension of the hopper was choosen to avoid frequent loading of the hopper, 10 kg of unshelled moringa seed was choosen as the equivalent weight.

A square pyramid with 400 mm upper base, 200 mm lower base and a height of 300mm was selected as shown in figure 1.Since the volume of material to be processed is equal to the actual volume of hopper which is $0.041\,m^3$ then the hopper can carry the volume of material it was designed for.

Determination of Total Power Requirement

The power required to operate the machine is a function of the total forces required to rotate decorticating drum, rotate the fan and the reciprocate the sieve in the shaker unit and this was calculated using equation 2.1 as reported by Gbabo *et al.* (2013)

$$P_T = \frac{2\pi}{60}\left(N_d T_d + N_c T_c + N_f T_f\right) \qquad (2)$$

Where N_d = rpm of the decorticating drum T_d = torque on the decorticating drum (Nm), N_c = rpm of the cam shaft, T_c = torque on the cam shaft (Nm).N_f =rpm of the cleaning fan and T_f = torque on the cleaning fan shaft (Nm),

The total force or weight on the shaft in the shelling unit and the cleaning units are given by;

$F_{ts} = (M_N + M_D + M_{PS})g$ (3)

$F_{tc} = (M_B + M_{PC})g$ (4)

Where, F_{ts} = the total force or weight on the shaft in the shelling unit and F_{tc} = the total force or weight on the shaft in the cleaning unit.

But torque (T) = is the product of force and its perpendicular distance to the line of action this implies that $T_d = F_d \times r_d$ (5)

$T_c = F_c \times r_c$ (6)

and$T_f = F_f \times r_f$ (7)

Where

F_w = force on the decorticating drum (N),

r_w= radius of the decorticating drum (m),

F_{cb} = force required to reciprocate the sieve in the shaker unit (N),

r_{cb}= radius of the cam (m),

F_f =force on the fan shaft (N) and

r_f =radius of the fan (m)

A 2 h_p Electric motor was selected.

Determination of belt length for power transmission

The length between the pulley were determined using equation

$L_i = 2C + {}^{\pi}/_{2}\ (D + d) + \frac{(D-d)^2}{4C}$ (8)

Where:

C = center to center distance between the shaft (m),

D = diameter of the driven pulley (m)

d = diameter of the driver pulley (m) and L = length of the V-belt (m).

Determination of V-belt tension

The tension in the belt was calculated using equations 7 - 9

$T = T_1 + T_C$ (9)

$T = \tau A$ (10)

And 2.3log $(T_1/T_2) = \mu^{\alpha\theta}$ (11)

Where:

T = maximum tension in the belt (N),

T_1 = tension in the tight side of the belt (N),

$T_c = mv^2$ = centrifugal tension in the belt (N),

μ = allowable stress of the belt (N/m^2),

A = cross-sectional area of the belt (m^2) and

T_2 = tension in the slack side of the belt (N)

Determination of shaft diameter

The shaft design was based on strength, a ductile material (mild steel shaft) (1030) was selected. Based on the loading, the stress that may be acting on the shaft could be either bending or axial stress. The design and determination of shaft was in accordance with Khurumi and Gupta (2007). Considering maximum stress theory (a machine member fail when the maximum shear stress at a point exceed the maximum allowable shear stress for the shaft material) (Khurmi and Gupta, 2007). Since shaft under consideration are solid shaft and are normally acted upon by gradual and sudden loads, equations 10.

$$d = (\frac{16}{T\pi}\sqrt{(K_b M_b)^2 + (K_t M_t)^2})^{\frac{1}{3}}$$

Where:

d = shaft diameter (m)

K_b = combined shock and fatigue factor applied to bending moment = 1.5 to 2.0 for load suddenly applied with minor shock.

K_t = combined shock and fatigue factor applied to torsional moment = 1.0 to 1.5 for load suddenly applied with minor shock and for shaft with key way τ_a = 56.25×10^8 N/m^2

M_b = maximum bending moment as applied to the shaft (Nm)

M_t = maximum twisting moment (Nm)

$M_t = (T_1 - T_2)R$ (11)

Where M_t, T_1, T_2 and R are maximum twisting moment (Nm), tension in the tight side of the belt (N), tension in the slack side of the belt (N) and radius of pulley on the shaft (m)

Design of the Cam shaft

The diameter of the cam shaft is govern by maximum shear theory (Khurmi and Gupta, 2007) as reported by Balami, *et. al.* (2014) and was determined using equation 12

$$d_c{}^3 = \frac{16T_c}{\pi\tau_{max}} \quad (12)$$

Where:

d_c = cam shaft diameter, (mm);

T_c = equivalent twisting moment, (Nm) and

τ_{max}= maximum shear stress,($\frac{N}{mm^2}$)

Determination of the cam velocity

The velocity of the cam (v_c) was calculated using equation 11

$$V_c = V_d h \frac{6N}{\beta} \quad (13)$$

Where:

V_c = cam velocity, (mms^{-2});

V_d = velocity coefficient at any point,

h = total displacement of the cam follower,(mm);

N = speed of the cam shaft, (rpm) and

β = angular displacement of the cam, (rad)

Design of the Decorticating Unit Clearance

The design of the decorticating unit clearance is one of the most important aspect in the design of a decorticating machine and was determined according toOnyechi*et al*. (2014) using the equation.

$$S_c = \frac{a+b}{2} \quad (14)$$

Where:

S_c =Shelling Unit Clearance,(mm)

a = The major diameter of the seed, (mm)

b =The minor diameter of the seed, (mm)

The technical characteristics of the machine is shown in table 4

Machine Construction Procedure

The frame was constructed using 50 x 50 x 6 mm mild steel angle iron which was cut into specified pieces of length to structure out the main frame of $800\times 500 \times 800\,mm$, forming an angle 90^0 on each end, the joints were tacked in position. The structure was giving room for necessary adjustment. The cylinder of diameter 300 mm was constructed using 2.0 mm thick mild steel sheet. A measure of 450mm × 942mm being the length and circumference of the drum was marked and cut to form the drum. Two circular disk of diameter 300mm each were also measured and cutout with 30mm hole at the center for the insertion of shaft. These disks were welded to the cylinder at both ends. The concave was made from 2.0 mm thick mild steel sheet. A length of $486\,mm \times 450\,mm$ was measured and cut. Holes of $11\,mm$ diameter $15\,mm$ apart were drilled into the sheet to form the concave of semi circular shape. This concave was then welded to the frame.

The space between the upper cover and lower cover that housed both cylinder and concave formed the decorticating space. The covers were made from a mild steel sheet of gauge 16. Two lengths of 500mm x 180mm were cut out and formed into a semi circular shape of radius 150mm to form the upper and lower covers of the cylinder. A sheet of $1200\,mm \times 300\,mm$ was also measured and cut to form the hopper of square pyramid ($400\,mm \times 300\,mm \times 200\,mm$). Lastly square hole of $200\,mm \times 200\,mm$ was measured and cut on the middle of upper cover to pave way for the insertion of the hopper, they were welded to the frame. The blower which consists of the blades, blades casing and blower shaft was constructed using Gauge 16 mild sheet with 25 mm diameter steel shaft of length 544 mm known as blower shaft. A piece of gauge 16 mild steel sheet measuring 400 mm x 680 mm were measured and cut to form the cylindrical blower housing and was welded to the involutes. Circle of 120mm diameter was measured and cut out at the centre of each involutes to serve as air inlet into the blower, Three number of 200mm x 450mm gauge 16 mild steel sheet was cut to form the fan blades which were welded to the shaft and finally they were all welded to the frame. The Winnowing Unit was formed using gauge 16 mild steel sheets which was marked and cut to the length of 950 mm x 400 mm and bend to form 350 x 300 x 350 mm trapezoidal shape. Sieves of Ø 9 mm and Ø11 mm diameter (geometric mean diameters of Moringa seed and kernel) and ½ angle iron of size 400 x 350 mm were used to form the sieving unit. V-belts of 50mm, 313mm and 165 mm were selected for prime mover, decorticating cylinder, blower and shaker units.

Final Assembly

The cylinder was positioned over the concave screen with holes corresponding to those on the main frame through the slots on the bearings housing and bolted using 19 mm bolts, nuts and washers then the hopper and the upper cover of the cylinder were bolted to the main frame using 13mm bolts and nuts. The main frame was permanently welded after which the outlets for clean grain and chaffs were welded to the shaker. The blower shaft with the bearing and attached blades were inserted into the blower housing and housing, this assembly was bolted to the frame in horizontal position. It was ensured that the blades are free before welding the second involutes. The shaker unit was placed under the concave on four (4) flat bars and bolted to the cam. The pulleys were fitted to the drive shafts and keyed, also the belts were fitted to the pulleys and the machine was ready to be operated. Figure 3.7 shows the Moringa decorticator. The orthographic view of the constructed machine is shown in figure 3.8 and the designed parts or components of the machine are shown in the figure 3.9.

Total cost of the Machine

Total cost of the machine was calculated using the empirical formula below

Total Cost (N) $= Material\ Cost + Miscellenious\ Cost\ + Labour\ Cost$

$Material\ Cost$ = 50,400

Miscellaneous Cost (N) = $5\%\ of\ the\ Material\ Cost = \frac{10}{100} \times 50{,}400 = 5{,}040$

Labour Cost (N) $= 20\%\ of\ the\ matrial\ cost = \frac{20}{100} \times 50{,}400 = 10{,}080 = 50{,}400 + 5{,}040\ + 10{,}080 = N\ 65{,}520$

Therefore the total cost for the production of moringa seed decorticating machine is in the tune of sixty five thousand five hundred and twenty naira only (N 65,520.00).The isometric, orthographic and pictorial view of the machine are shown on figures 2, 3 and plate II respectively.

Machine evaluation procedure

The machine was first run under no-load condition using an electric motor of 3hp with speed rating of 1440 rpm, whereas the metallic drum shaft was run at a speed of 240 rpm under the no-load condition. Essentially, the no-load test was carried out to ascertain the smoothness of operation for the machines rotating parts. The actual test was conducted using moringaoliefera seed. Testing of the machine was targeted at evaluating its shelling efficiency, cleaning efficiency, and percentage losses and seed recovery rate. About fifty kilogram (54 Kg) of moringa seed was obtained from NARICT in Zaria and Uzo Uwani of Enugu State and were divided into three equal measures of 1000 g, 2000 g, and 3000 g each for both large and small castor pods. The performance test was conducted for each accession of castor pod using those data. The results obtained were analyzed using analysis of variance (ANOVA).

Experimental Design

A two - variable, three - level full factorial design ($N = 3^2$) provides the framework for the experiments. With two factors and three levels, an orthogonalised design leads to a total of nine experimental runs. In the 3^2 full factorial experiment the low, medium and high levels of the factors were coded as (−), (0) and (+) respectively as reported by Olorunsogo and Adgidzi (2010). The 3^2 full factorial experiment will be conducted in a randomized order in three replications as given in the design matrix in Table 3.The data collected will be used to determine the analysis of variance (ANOVA) using SPSS 15.0.

Results and Discussion

Result of Performance Evaluation of the Machine

Results for the machine evaluation parameters at three speed levels of 230 rpm, 330 rpm and 430 rpm and at three moisture content levels of 7 %, 10 % and 13 % respectively are presented in Table 1.The average decorticating efficiency was 88 %. The average percentage of the undecorticated seeds is 4.9 %, this also indicate a good result as comparing this with the percentage of the seeds decorticated is negligible. The average blower loses was 1.2 % of the total mass (1 kg) of the seeds introduced into the machine which is minimal therefore, gives a good result. The average cleaning efficiency of the machine was found to be 86.4% which is higher than the value 48.74 % reported by Balami *et al.* (2012) for castor seed decorticating machine, this value is also however lower than the values (91.67 % and

96.24 %) reported by Onyechi *et al*. (2014) for ground nut and castor seeds shelling machine respectively. The kernel recovery efficiency is 91.31 % which indicates a good result and almost in agreement with 99.50% reported by Balami*et al*. (2012) for castor seed shelling machine.

Statistical Analysis

The Analysis of variance (ANOVA) results as presented in Tables 2 and 3 shows that the moisture contents and speed of the machine have a significant effect on both the decorticating and cleaning efficiencies of the machine ($P < 0.05$). This means that the speed and moisture content as singular factor significantly affect the decorticating and cleaning efficiencies of the machine. The interaction between the speeds and moisture contents (x_1x_2) do not have significant effect on decorticating and cleaning efficiencies ($P < 0.05$). This means that the interaction of the two factors do not have any effect on the decorticating and cleaning efficiencies of the machine.

Conclusion

The machine was successfully constructed and evaluated. The performance evaluation of the machine at three speeds of 230, 330 and 430 rpm and at three moisture contents of 7%, 10% and 13% and concave clearance of 11mm gave an average decorticating and cleaning efficiencies of 88.00 % and 86.40 %. The average blower losses were 2.29 %, the average undecorticated seed of 16.00 % and the average kernel recovery efficiency of 97.70%. However, the highest decorticating efficiency of95.07 % was obtained at 330 rpm and 7% moisture content while the lowest 78.50% was obtained at 330 rpm and 13 %. The highest and lowest cleaning efficiencies of 92.20% and 79.20% were obtained at 430 rpm, 10%, 230 rpm and 13% respectively. The highest and lowest kernel recovery efficiencies of 98.27 % and 90.33% were obtained at 330 rpm, 10 %, 430 rpm and 7 % speed and moisture content respectively. The lowest and highest total losses of 1.73 % and 2.45 % were obtained at the speeds and moisture content of 430 rpm, 10 %, 330 rpm and 10 % respectively.

The Analysis of variance (ANOVA) results revealed that the moisture contents and speeds have a significant effect on both the decorticating and cleaning efficiencies of the machine at ($P < 0.05$), though the interactions between the factors (speeds and moisture contents) (x_1x_2) do not show any significant effect on decorticating and cleaning efficiencies at ($P < 0.05$).

The developed machine has a throughput capacity of 480 kg per day as against the hand decortications of 5kg per day (Anantachar*etal*. 1997), which means that the machine will reduce drudgery, save time and increase Moringa seed decortications, thereby encouraging Moringa seed farmers to go into mass production.

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Table 1. Machine Evaluation Parameters at different Speeds and Moisture Contents

Evaluation Parameter	Average values at different speeds and Moisture Content								
Speeds (rpm)	230	330	430	230	330	430	230	330	430
Moisture contents (%)		7%			10%			13%	
Total loses (%)	2.29	2.25	2.52	2.15	1.73	2.45	2.09	1.96	2.94
Undecorticated seeds (%)	16	5	9.7	19.1	5.57	10.4	16.7	5.93	11.97
Kernel recovery (%)	97.7	97.8	90.33	97.85	98.29	97.5	97.9	98.14	97.06
Decorticating Efficiency (%)	81.4	95.07	90.3	80.9	94.3	89.6	78.5	93.7	88.03
Cleanliness Efficiency (%)	86.1	85.7	89.8	86.8	92.2	79.2	79.2	84.1	87.2

Table 2. Analysis of Variance (ANOVA), decorticating efficiency (DE)

Source	Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	943.347(a)	8	117.918	64.580	0.000
Intercept	209,017.606	1	209,017.606	114,472.117	0.000
x_1	22.716	2	11.358	6.220	0.009
x_2	917.772	2	458.886	251.317	0.000
$x_1 x_2$	2.859	4	0.715	0.391	0.812
Error	32.867	18	1.826		
Total	209,993.820	27			
Corrected Total	976.214	26			

R^2 = 0.966 (Adjusted R^2 = 0 .951) P < 0.05; df = degree of freedom and F = calculated F value

Table 3: Analysis of Variance (ANOVA) for the Cleaning Efficiency, CE

Source	Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	313.290(a)	8	39.161	3.398	0.015
Intercept	202,003.450	1	202,003.450	17,528.259	0.000
x_1	129.921	2	64.960	5.637	0.013
x_2	155.436	2	77.718	6.744	0.007
x_1x_2	27.933	4	6.983	0.606	0.663
Error	207.440	18	11.524		
Total	202,524.180	27			
Corrected Total	520.730	26			

a. R Squared = 0 .966 (Adjusted R Squared = 0.951), P < 0.05; ; df = degree of freedom and F = calculated F value

Table 4: Technical Characteristics of the Moringa Seed Decorticating Machine

Description	Values
A Dimensions	
Overall width, mm	500
Overall Length, mm	800
Machine height, mm	1350
B Electric Motor capacity	5 Hp
C Blower	
Fan Housing diameter, mm	300
Fan housing width, mm	400
Fan speed, rpm	1107
Number of fan blades	3
D Concave	
Concave clearance, mm	11
E Separating Cylinder dimensions	
Lengths, mm	450
Diameter, mm	300
F Decorticating cylinder speed, rpm 230	
G Number of sieves 2	
Diameter of sieve holes, mm	ɸ11 and ɸ9

The machine could be powered using diesel or gasoline engine

Table 5. Design Matrix for a 3^2 Full Factorial Experiment

Run	x_0	x_1	x_2
1	+	−	−
2	+	0	−
3	+	+	−
4	+	−	0
5	+	0	0
6	+	+	0
7	+	−	+
8	+	0	+
9	+	+	+

x_0= Dummy Variable, x_1 = Moisture Content (%) and x_2 =Shelling Speed (rpm)

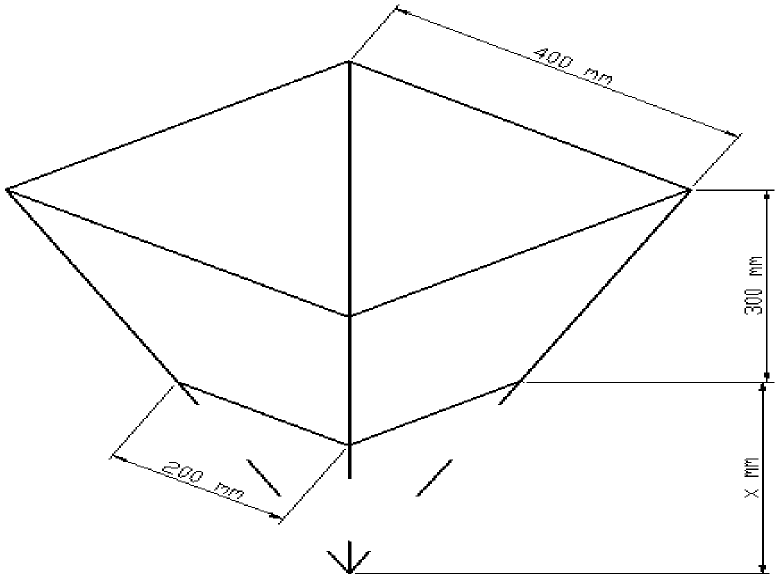

Fig 1: The Hopper dimensions

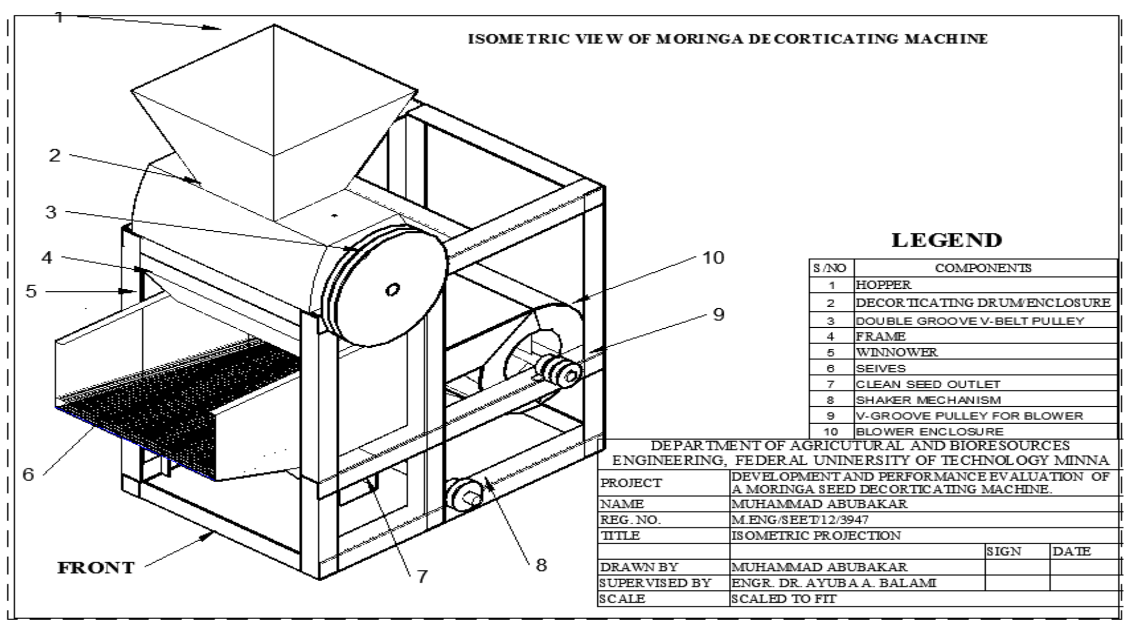

Figure 2. Isometric View

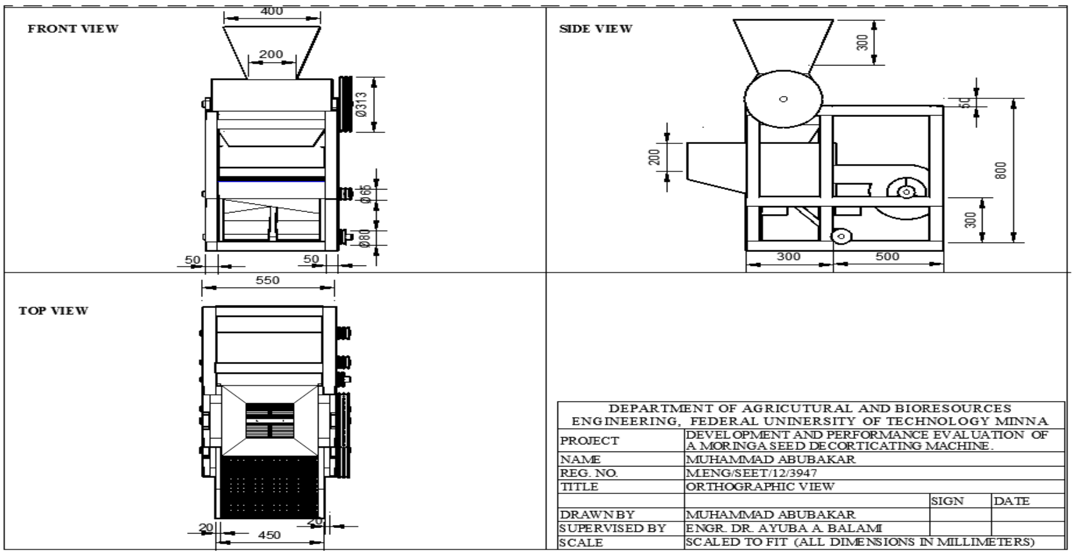

Figure 3. Orthographic View

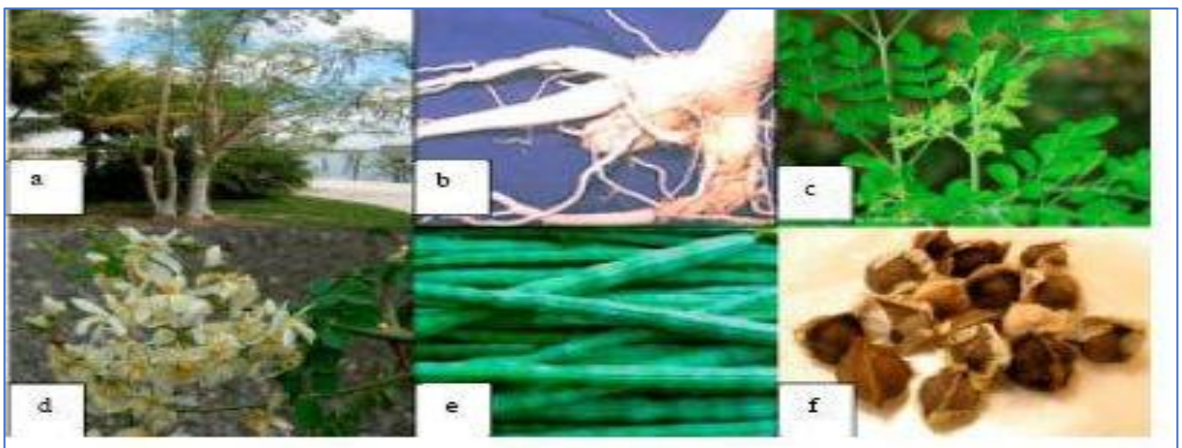

Plate1. Moringa Tree products,
Source: Ritu, Veena and Pracheta (2011).
Legend: a = Moringa tree, b = Moringa Roots, c = Moringa Leave, d = Moringa Flower, e = Moringa Fruits, f = Moringa Seeds, g = Moringa kernel

Plate 2. Picture of the machine
Source: author's camera