DEVELOPMENT AND PERFORMANCE EVALUATION OF A MORINGA(*OLIEFERA*) SEED DECORTICATING MACHINE

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ABSTRACT:
This study is about the development and performance evaluation of a machine for decorticating Moringa oliefera seeds. Performance tests were carried out using three levels of moisture contents (7.35, 10.35 and 13.35 %) and at three levels of speeds (230 rpm, 330 rpm and 430 rpm), each one replicated three times. The optimum decorticating and cleaning efficiencies of 95.07 and 92.20 % respectively were obtained at 330 rpm and 7.35 % speed and moisture content respectively. The blower losses were 2.29 % and the undecorticated seeds was 16 %. The average kernel recovery efficiency was found to be 97.7 %. The analysis of variance (ANOVA) showed that the moisture content and speed have significant effect on both the decorticating and cleaning efficiencies of the machine at (P < 0.05), there was no interaction between the factors. The developed machine will reduce the drudgery involved in manual decortication and will save about 70 % operating time.

Key words: Moringa *oliefera, decorticating machine, kernel recovery, decorticating and cleaning efficiencies*

1. INTRODUCTION

Moringa *(oliefera)* belongs to a monogenetic family, called the Moringaceae and is also known as Miracle tree. It is indigenous to south Asia, where it grows in the Himalayan foothills from North Eastern Pakistan to North Western Bengal, India (Sharma, et al., 2011). It has been introduced and is grown in other parts of the world. 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). Moringa known commonly as Horseradish tree, is also known as "OkweOyibo" in Igbo, "Gawara"or Habowal" or zogelle" in Hausa and "Adagbamaloye" or "Ewe Igbale" in Yoruba. It grows rapidly in most regions and climatic conditions of Nigeria and throughout the world. Moringa is an important food commodity which has commanded enormous attention as the natural nutrition of the tropics (Anwar et al., 2007).

Fahey (2005) reported that Moringa is a fast-growing tree that is grown for human food, medicine, dye, fodder and water clarification. It has an impressive range of medicinal uses with high nutritional values. 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 Fuglie (1999), the many uses of Moringa includes: alley cropping (biomass production), 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; it can also tolerate a wide range of soil and rainfall conditions. Various varieties of Moringa *oleifera* have been developed to meet the tastes of local populations (Anwar and Bhanger, 2003).

Olajide (2000) reported that Moringa is an oil seed that contains Ben oil within the range of 35 – 40 %. Oil seeds are important components of tropical agriculture as they provide readily available and highly nutritious elements for human and animal foods. Some oil seeds have hard outer shell which must be removed before processing. This process is called decortication. Moringa seed is an example of a seed that must be decorticated prior to processing. The unit operations involved in the oilseed processing are decortications, seed cleaning, size reduction, rolling, conditioning and oil extraction (NRI, 1995). 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 (Olajide, 2000).

In Nigeria especially in the north, it is mostly planted around local houses and is used as fence. It can grow up to 36 feet in height and can live up to twenty years if undisturbed. Due to its nutritional, therapeutic and prophylactic benefits, it is widely promoted in poverty stricken areas to counter malnutrition and the effect can be noticed within a few days of adding it to the diet.

In Nigeria the method of decorticating Moringa *oliefera* seed is by manual means which is achieved through pounding using pestle and mortar after sun drying. This method is not only inefficient but also very laborious and the output is low about 0.005 tonnes/day (Anantachar, 1997). This brings about delay in handling large volumes of Moringa *oliefera* harvests and subsequently leading to losses. Fig. 1 shows Moringa *oliefera* tree and its product. For the aforementioned reasons, there is need to develop and carry out the performance evaluation of a Moringa *oleifera* seed decorticating machine to help in addressing this problem.

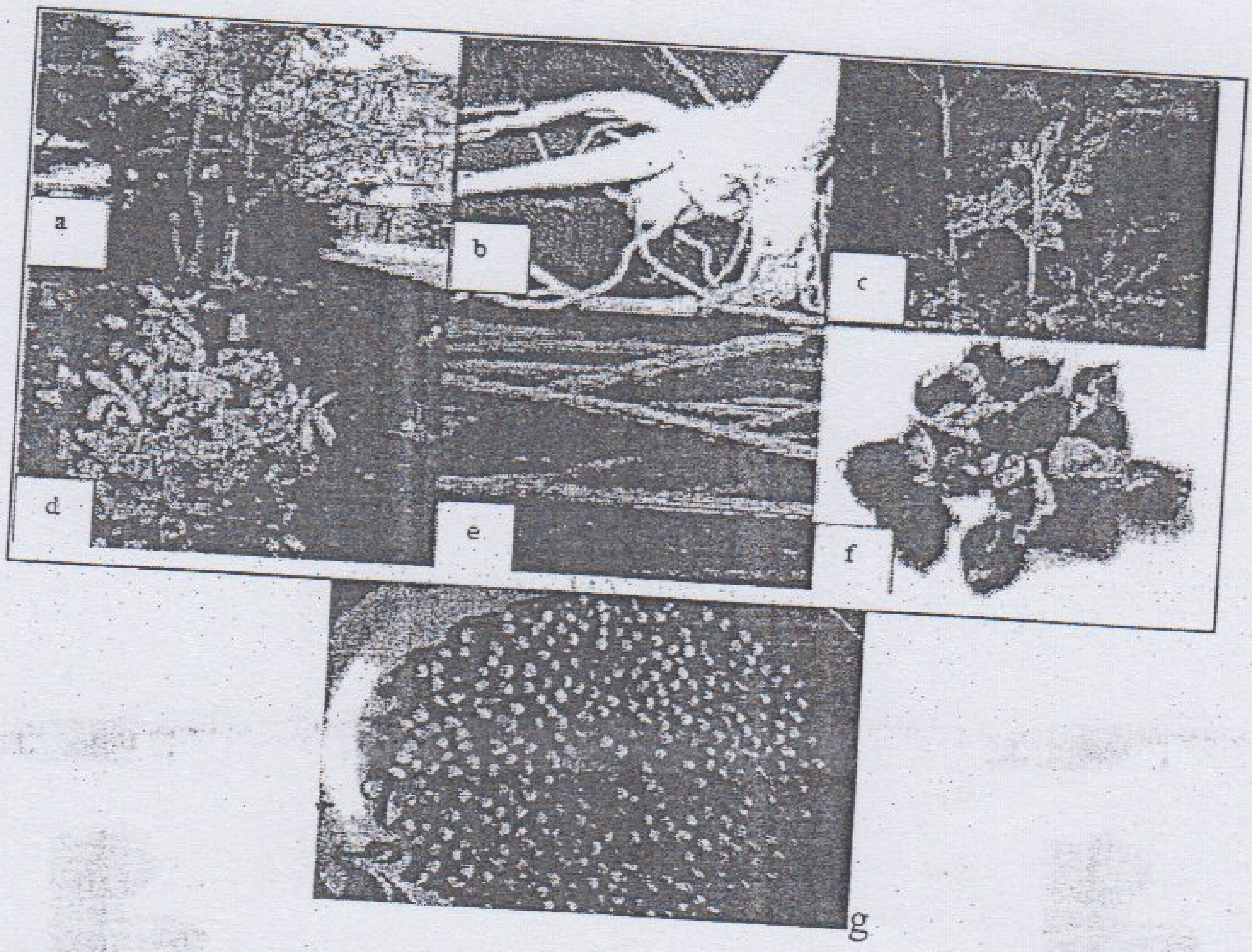

Figure 1: Moringa *oliefera* Tree and its products

Source: Ritu et al. (2011).

Legend: a= Moringa tree, b= Moringa Roots, c = Moringa Leave, d= Moringa Flower, e = Moringa Fruits, f= Moringa Seeds, g = Moringa kernel

2. MATERIALS AND METHODS

2.1.1 Material selection

The materials used for the construction of the decorticating machine were sourced locally and selected based on their availability, cost, suitability and viability in service among other considerations (ASAE, 2003; Balami *et al.,* 2014).

2.1.2 Power Requirement of the Machine

The power required to operate the machine is a function of the total force required to rotate the shelling drum and to operate the fan in the cleaning unit as reported by Gbabo *et al.,* (2013). Therefore, the power (P_T) was calculated using Equation 1.

$$P_T = \frac{2\pi N \tau_T}{60} \quad (1)$$

Where, P_T = the total power required by the machine (Kw)

$\tau_T = \tau_s + \tau_c + \tau_{sh}$ = Total torque ($N\ m$)

But

$\tau_s = F_{ts} \times r_d$ =Torque in the decorticating unit

$\tau_c = F_{tc} \times r_f$ =Torque in the cleaning unit and

$\tau_{sh} = F_{tsh} \times r_c$ = Torque in shaker unit

The total force or weight, (F_{ts}) on the shaft in the decorticating unit becomes;

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

Where;

M_N = the mass of the Moringa *oliefera* seed to be processed (kg)

M_D = The mass of the shelling drum (kg)

M_{PS} = The mass of the pulley in shelling unit (kg)

g = acceleration due to gravity (m/s^2)

The total weight(F_{tc}) on the shaft in the cleaning unit becomes

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

Where: M_B = The mass of the blades in the cleaning unit (kg)

M_I = the mass of the iron bar in the cleaning unit (kg)

M_{PC} = The mass of the pulley in the cleaning unit (kg)

The total force or weight (F_{tsh}) required to reciprocate the shaker unit becomes

$$F_{tsh} = (M_{rt} d r \omega^2)$$

Where;

M_{rt} = Total mass to be reciprocated in the shaker unit (kg)

d_r = The diameter of the pulley in the shaker unit (kg)

ω = Angular velocity of the shaft in the shaker unit (rad/s)

r_d = Radius of the shelling drum (m)

r_f = Radius of the fan in the cleaning unit (m)

r_c = Radius of the base circle of the cam (m)

g = acceleration due to gravity (ms^{-2})
N = The speed of the electric motor in revolution per minutes (rpm)

2.1.3 Determination of Mass of the Decorticating Drum

The total mass of the drum (M_D) is essential in the determination of the power requirement of the machine as reported by Gana (2011) and is given in the Equation 2. The drum consists of mild steel blades welded to two circular plates at both ends.

$M_D = M_{CP} + M_{MB}$ (2)

$M_{CP} = \sigma(\pi r_a^2 h_a)N_c =$ The mass of the circular plate (kg)

$M_{MB} = \sigma(L_c B_c T_c) =$ The mass of the blades (kg)

But, B_c = circumference of the drum = $2\pi r$

$M_D = \sigma(\pi r_a^2 h_a)N_c + \sigma(L_c B_c T_c)$

Where: σ = the density of mild steel, (kg/m^3)
r_a = the radius of the circular plate (m)
t_a= the thickness of the circular plate (m)
N_c = the number of circular plates
L_c = the length of the blade, (m)
B_c = the breadth of the blade (m) $= 2\pi r_a$
T_c = the thickness of the blade (m)

2.1.4 The Machine Pulley

The decorticating speed ranging from 100 – 450 rpm had been used by researchers such as Francis (2012); Ikechukwu et al. (2014), Balami et al. (2012), Balami et al. (2014); Bashir et al. (2013) and Onyechi et al. (2014). Therefore, for this design, machine speeds of 230, 330 and 430 rpm were selected to ascertain the optimum speed for the decorticating drum. The power requirement of the machine was determined to be 4.5 hp hence 5 hp electric motor was selected.

The diameters of the machine pulleys at the three selected speeds of the electric motor were determined using Equation 3 (Gana *et al.*, 2013).

$N_1 D_1 = N_2 D_2$ (3)

But, $D_2 = \frac{N_1 D_1}{N_2}$

Where, N_1 = the speed of the electric motor (rpm)
D_1 = diameter of the electric motor pulley (m)
N_2 = the speed of the machine pulley (rpm) and
D_2, D_3 *and* D_4 = the diameters of the machine pulleys (m) at the three selected machine speeds.

2.1.5 Determination of the Blower Blade Diameter

A blower blade with 90° blade tip was selected because it can be easily constructed and has the ability to convey large volume of air high pressure (Balami et al., 2014: Sitkei, 1986). This was determined using equation 4.

$Q_t = \pi d_b W_b V_{2r}$
(4)

Where Q_t = Theoretical air discharge (m^3/s)
d_b = Diameter of the blade (m)
W_b = Width of the blade (m)
V_{2r} = Tangential component of the absolute velocity (m/s)

2.1.6 Determination of the Blower Casing Diameter and Width

The blower casing diameter and the blower casing width were determined using Equations 5 and 6 as reported by Balami *et al*. (2014).

$$D_c = 1.5D_b \quad (5)$$

$$C_c = 1.25W_b + 0.1D_b \quad (6)$$

Where D_c = Diameter of the blower casing (m)
D_b = Diameter of the blower blade (m)
C_c = Width of the blower casing (m)
W_b = Width of the blower casing (m)

2.1.7 Design of shaker unit

The shaker unit is made up of the sieve compartment, iron bars bolted to the sieve compartment, cam shaft, pulley and the cam cone. The force (F_r) required to reciprocate the sieve was calculated using the Equation 6 as reported by Fayose (2008).

$$F_r = M_{rt}dr\omega^2 \quad (7)$$

Where: $M_{rt} = M_{sc} + M_{ms}$ = total mass to be reciprocated (kg)
$M_{sc} = M_{ms} + M_s$ = total mass of sieve compartment (kg)
$M_{ms} = \rho_{ms}V_{ms}$ = mass of metal sheet used in forming the sieve compartment (kg)
$M_s = N_s\,(\rho_sV_s)$
$M_{rt} = \rho_{ms}V_{ms} + N_s\,(\rho_sV_s)$
Also,
$V_s = B_sL_sT_s$
And $V_{ms} = \frac{1}{2}(a + A) \times B \times H$
$M_{sc} = \rho_{ms}\frac{1}{2}(a + A) \times B \times H + N_s\,(\rho_sB_sL_sT_s)$
Where: d = diameter of pulley in shaker unit (m)
r = radius of the camshaft (m)
M_m = mass of Moringa *oliefera* seed to be processed (kg)
ρ_{ms} = density of mild steel sheet (k/m^3)
V_{ms} = volume of trapezoidal sieve compartment (m^3)
N_s = Number of sieve
ρ_s = density of mild steel sieve (kg/m^3)
V_s = volume of sieve (m^3)
A and a = the two parallel sides (m)
B = breath of the sieve compartment (m)
H = height of the sieve compartment (m)
L_s = length of sieve (m)
B_s = breath of the sieve (m)
T_s = thickness of the sieve (m)
$\omega = \frac{2 \times \pi \times n}{60}$
Where n = Speed of the cam shaft (rpm)

2.1.8 Design of the Decorticating Unit Clearance

The design of the decorticating unit clearance is one of most important aspect in the design of a decorticating machine and this was determined using equation 8 as reported by Onyechi *et al*. (2014).

Shelling Unit Clearance $= \frac{a+b}{2}$ (8)

Where: a = The major diameter of the seed (mm); b =The minor diameter of the seed (mm)

2.1.9 Centre Distance of Motor – Cylinder Pulleys

The centre distance of motor – cylinder pulleys was determined using the relationship in equation 9 as reported by Dauda (2003).

C_d= max (2R; 3r + R) (9)

Where: R = the radius of larger pulley (mm); r = the radius of small pulley (m)

2.1.10 Length of Motor – Cylinder Belt

The length of motor-cylinder belt was obtained from equation 10.

$$L = 2C_d + \pi \left(\frac{D_1+D_2}{2}\right) + \left(\frac{D_1-D_2}{4C}\right)^2 \quad (10)$$

Where C_d = center distance (m); D_1= diameter of driver pulley (mm); D_2 = diameter of driven pulley (mm)

The closest value to the calculated length from table is 1255 mm.

The actual value of centre distance (C_A) is given by equation 11.

$$C_A = P + \sqrt{p^2 - q} \quad (11)$$

Where: $P = \frac{L}{4} - \frac{\pi}{8}(D_1 + D_2)$

$q = (D_1 - D_2)^2$

2.1.11 Determination of Decorticating Cylinder Shaft Diameter

The diameter of the shaft was calculated using equation 12 as reported by Khurmi and Gupta, (2007).

$$d^3 = \frac{16}{\pi s_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (12)$$

Where: d = diameter of the shaft (mm); Ss = allowable stress (N/m^2)

K_b, Kt = Combined shock and fatigue factor applied to bending and torsional moments

M_t = Maximum twisting moment (Nm)

2.1.12 Principle of Operation of the Machine

The Moringa *oliefera* seeds decorticating machine (Fig. 2) mainly consists of decorticating and separating (blower and the shaker) units which is operated by a 5 hp electric motor. A blower was incorporated to facilitate easy and proper separation of the kernels from the decorticated particles. As the moringa seeds are introduced into the decorticating chamber through the hopper, the seeds got decorticated as a result of the rubbing action that occurred between the drum and the concave. After being decorticated, the decorticated seeds and the chaffs move down to the set of sieves which are separated with the help of airstream from blower and reciprocating action of the shaker. The clean kernels were finally collected at the outlet port. The technical characteristics of the machine are given in Table 1.

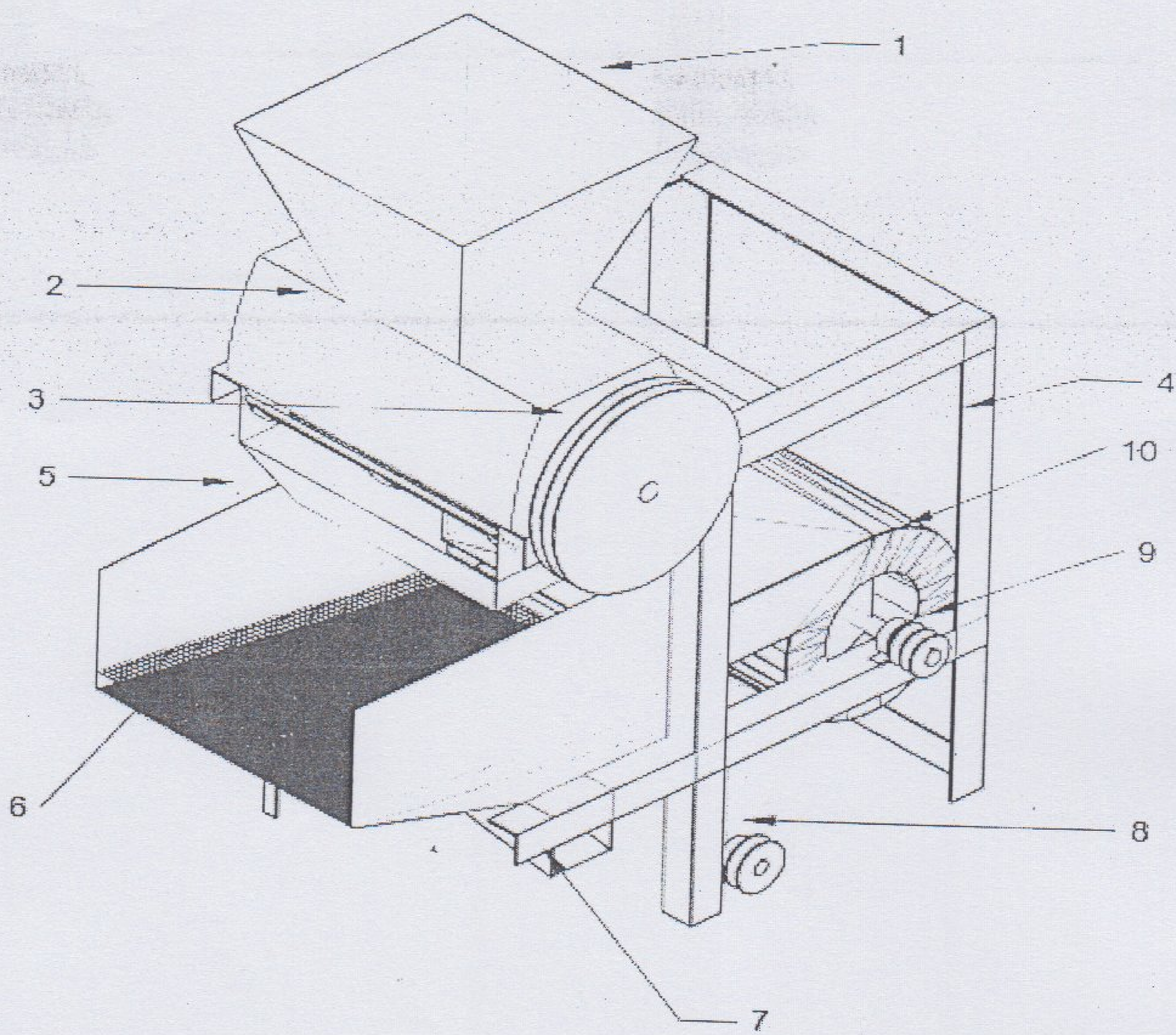

Figure 2: The Moringa *oliefera* seeds decorticating machine

Legend: 1 - Hpper, 2 - Drum casing; 3 - Double grooved V - belt pulley; 4 - Frame, 5 - Air outlet; 6 – Sieves; 7 - Kernel Outlet; 8 - Shaker Mechanism; 9 - V-grooved pulley for the blower; 1 0 -Blower casing

Table 1: Technical Characteristics of the Moringa Seed Decorticating Machine

Parameters	Values
Overall width, mm	500
Overall Length, mm	800
Machine height, mm	1350
Fan Housing diameter, mm	300
Fan housing width, mm	400
Fan speed, rpm	1107
Number of fan blades	3
Electric Motor capacity	5Hp
Concave clearance, mm	11
Separating Cylinder dimensions	
Lengths, mm	450
Diameter, mm	300
Number of sieves	2
Diameter of sieves, mm	ϕ11 and ϕ9

2.1.13 Experimental Design

A two-variable, three-level full factorial design ($N = 3^2$) provides the framework for the experiments. The design matrix for the 3^2 full factorial experiment is shown in Table 2. The data were collected in a randomised order in three replications as reported by Olorunsogo and Agidzi (2010).

Table 2: Design Matrix for a 3^2 Full Factorial Experiment *2: Design Ma*

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 = Decorticating Speed (rpm)

2.1.14 Machine Evaluation

The machine was evaluated at three different speeds of 230 rpm, 330 rpm and 430 rpm respectively and at three different seeds moisture contents of 7.35, 10.35 and 13.35 % (wb). The moisture content of the seed was determined using the oven dry method (ASAE, 2003). In order to achieve the desired moisture content, the seeds in three separate polyethylene bags were conditioned. The samples were kept for a week and two weeks for the moisture to distribute uniformly throughout the seed (Carman, 1996). The seeds were then fed into the machine for decorticating and cleaning. The experiment was replicated thrice. The quantity of the seeds collected at the collecting chutes were recorded and the decorticating efficiency, cleaning efficiency and the throughput capacity (kg/h) were determined using Equations 13, 14 and 15 as reported by Adejumo and Abayomi (2012) and Donahue et al. (1999).

$$Decorticating\ efficiency\ (\%) = (1 - \frac{Mass\ of\ undecorticated\ seeds}{Total\ mass\ of\ sample}) \times 100 \quad (13)$$

$$Cleaning\ efficiency\ (\%) = (1 - \frac{Total\ mass\ of\ impurities}{Total\ mass\ of\ clean\ kernels}) \times 100 \quad (14)$$

$$\text{The throughput capacity (kg/h)} = \frac{S_1}{T_M}$$

(15)

Where: S_1 = total mass of clean and unclean nut (kg), T_m = time of cleaning (h)

3. RESULTS AND DISCUSSION

Results of the machine evaluated parameters at speed levels of 230 rpm. 330 rpm and 430 rpm and moisture content of 7.35 %, 10.35 % and 13.35 %, respectively, are presented in Table 3. From the results the average decorticating efficiency was 88 %. The average percentage of the undecorticated seeds was 4.9 %. The average blower loses was 1.2 % of the total quantity of the seeds introduced into the machine. The average cleaning efficiency of the machine was found to be 86.40 %. The kernel recovery efficiency is 91.31 %. The highest decorticating efficiency of 95.07 % was obtained at 330 rpm and 7.35 % 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, at 10.35 %, 230 rpm and 13.35 % respectively. The highest and lowest kernel recovery efficiencies of 98.27 % and 90.33 % were obtained at 330 rpm, 10.35 %, 430 rpm and 7.35 % 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, 10.35 %, 330 rpm and 10.35 % respectively.

The developed machine has a through put capacity of 480 kg per day as against the manual decortication of 5 kg per day (Anantachar et al., 1997), which means that the machine will reduce drudgery and save time, thereby encouraging Moringa *oliefera* seeds farmers to go into mass production.

Table 3: 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 (%)		7.35 %			10.35 %			13.35 %	
Total loses (%)	2.29	2.25	2.52	2.15	1.73	2.45	2.09	1.96	2.94
Undecorticated seeds (%)	16	5.0	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	97.53	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

3.2 Results for the Analysis of variance (ANOVA)

The Analysis of variance (ANOVA) results are presented in Tables 4 and 5; the result showed that the moisture content and speed of the machine have significant effect on decorticating and cleaning efficiencies of the machine (P < 0.05). This indicates that the speed and moisture content as singular factors significantly affect the decorticating and cleaning efficiencies of the machine. The interaction between speed and moisture content (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.

Table 4: 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_1x_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 5: 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

4. CONCLUSION

A Moringa *oliefera* seeds decorticating machine has been developed and evaluated. Test results of the machine revealed that the highest decorticating efficiency of 95.07 % was obtained at 330 rpm and 7.35 % speed and moisture content respectively while the highest cleaning efficiency of 92.20 % was obtained at 330 rpm and 10.35 % respectively. The machine performance revealed a satisfactory performance and it is found suitable for decorticating Moringa seeds.

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