DEVELOPMENT AND PERFORMANCE EVALUATION OF CASSAVA MASH SIFTING MACHINE

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Abstract

Sifting is an essential process in the production of gari, which is one of the major products of cassava in Nigeria. It is necessary to sift before garification to remove oversized grain fractions. However, manual cassava mash sieving induces drudgery, fatigue, and time wastage during the processing. So, there is need to developed sifting machine to enhance the productivity and reduce drudgery.A motorized sieving machine for grated and dewatered cassava mash (gari) was developed and tested. The machine was powered by an electric motor and it was evaluated at three operating speed of 900 rpm, 699 rpm and 480 rpm respectively, with loading rate of 10 kg per run for performance test. It was discovered that the sifting capacity and sifting efficiency of the machine increased to 145.6 kg/h and 92% respectively requiring engine power of 1.815 KW. Also, increase in speed of operation improved both the sifting capacity and sifting efficiency of the machine.Both speed of operation and loading had significant effects on the magnitude of sifting capacity and sifting efficiency. The increase in sifting capacity was due to the fact that increase in speed led to more sifting of the cassava mash by the machine, hence the gari particles moved faster through the screen apertures. All materials used for fabrication were obtained locally and the estimated cost of production of a unit of the sifting machine is eighty-two thousand and five hundred naira (₦82,500), which should be affordable for local processor.

Keywords: cassava mash, sifting capacity, sifting efficiency, screen apertures

1. Introduction

Although cassava has its origin at South America, it is now extensively cultivated as annual crop in many tropical and subtropical regions of the world, including Africa, India and Indonesia, with Africa being the largest centre of production. Africa accounts for 51%, Asia 29%, Latin America and the Caribbean 20% of world production (FAO, 2007). Nigeria cassava production is by far the largest in the world, a third more than production in Brazil and almost double the production of Indonesia and Thailand (IFAD/FAO, 2004). Cassava production in Nigeria reached a peak of 45 million metric tonnes by the year 2015 to become the largest producer in the world (OBG, 2016).

Cassava tuber can be processed into many products such as; 'gari', 'fufu', cassava flour, cassava starch, ethanol, adhesives etc. (CIGR, 1998). However, 'gari' is the most popular product from cassava which is consumed by several millions of people in the West Africa sub-continent of Africa (Ofuya and Akpoti, 1988; IFAD/FAO, 2004). It is often consumed as main meal in the form of dough or a thin porridge and both are prepared by mixing dry gari with hot or cold water, and are served with soup or stew.

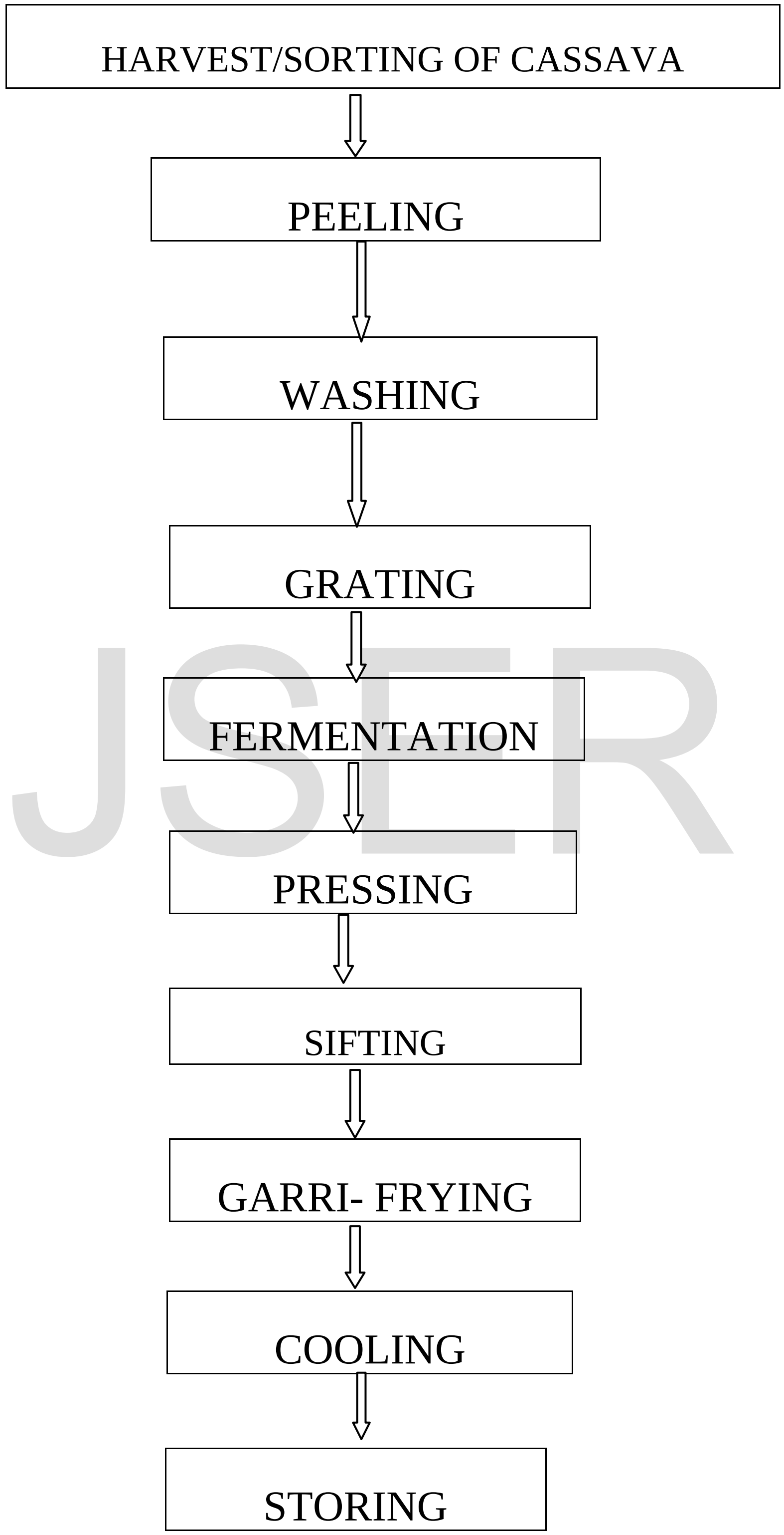

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Fig.1: Flow Chart for Gari Processing (IITA,2005).

Cassava tuber processing into gari involves stages such as; tuber washing, peeling, grating/chipping, pressing or dewatering, sifting, drying/frying, and packing as shown in Fig.1 Gari production processes are laborious and cumbersome, with the production method varying from one locality to another, resulting in product of non-uniform quality.

Traditional processing is carried out mainly by women and it requires high labour input, also it is time consuming especially the peeling, grating and sifting operation (IITA, 1990). Sifting is a very important operation in gari production. It is the pulverization of pressed mash carried out as a necessary measure to achieving efficient heat transfer during frying. It is equally important as it ensures the homogeneity of the finished product and reduces the energy required during frying operation (Hillocks, 2002). Manual sieving method using raffia sieve is still dominant in the study area, and this has a major problem of the sifting position because it requires bending and stretching which result in aches and pain on the person carrying out the sifting operation (Ali et al, 2003). In order to solve these problems in 'gari' industry, there is a need to develop a gari sifting machine. Therefore, the aim of this study was to develop a cassava mash sifting machine for use in gari local processing industry.

2. Materials and Methods

The design of a machine such as cassava mash sifter requires a careful consideration of the choice of materials to be used. The materials used for each part were selected based on the physical and chemical properties of the cassava mash to be sifted, machinability of the material, corrosion resistance and cost.

2.1 Design Considerations

The design of the machine was based on the following considerations;

(i) Availability of the materials locally to reduce the cost of production
(ii) Strength of the materials used for fabrication.
(iii) The size and shape of the material to be processed.
(iv) Choice of stainless materials for sifting and to prevent corrosion, cassava mash contamination and stain.
(v) The hopper was made to be closed-type to allow easy loading, so that the cassava mash is directed towards the lumps breaking rod wedded to the sifting shaft powered by the electric motor.
(vi) The sifted cassava mash outlet was inclined at an angle greater than the repose angle of the material for effective discharge.
(vii) The choice of pulley was carefully considered to meet the required speed of sieving unit and, to minimize loss of material during operation.

2.2 Machine Features and Description

The cassava mash sifting machine as shown in Fig. 2 consists of the following major component parts; the frame, sieving unit, hopper, pulley, bearing, electric motor frame, collecting chamber, sifting brush, and sifting shaft. The frame is the main unit of the machine on which all other components of the machine were supported. It was fabricated using high strength metal to withstand vibration, from mild steel angle iron of 5 mm thickness. The rectangular angle iron was firmly joined together with arc welding operation. The sieving unit was made of stainless steel metal sheet screen, flat bar and 20 mm diameter rod. The shaft is 25 mm diameter, 1200 mm long, and was supported with bearings at both ends. The shaft passed through the centre of the sifting chamber. The bearings were bolted to the flat bar welded directly to the angle frame and the housing fabricated from mild steel pipe with 25 mm bore, its width and thickness is accordance with the International Standard Organization (ISO) recommendation. The collecting chamber was made of stainless steel metal sheet. It was folded below the sieve and projected at angle of 45^o to the horizontal, for easy discharge of the sieved cassava mash through the outlet.

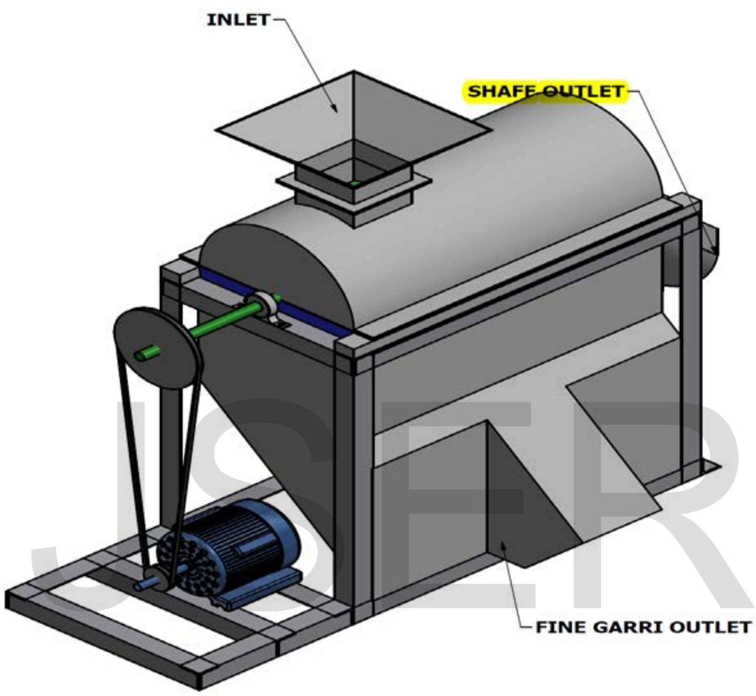

Fig. 2: Pictorial view of the cassava mash sifting machine.

2.3 Principle of the Machine Operation

When the belt system of the electric motor transmit rotary motion to the shaft of the machine, the sifting brush as well as the lump breaking rod receive power and results in its rotary motion. This makes the cassava mash lumps to be broken, the sifting brush simultaneously convey the cassava mash to the top of the sieve thereby creating forces from the brush and the sieve to sift the mash. Consequently, the sieved cassava mash pass to the collecting chamber and move out through the outlet. The sieved residue also passed out through the sieved residue outlet.

2.4 Design Parameters and Analysis

(i) The Frame**:** The frame is of dimensions 900 × 500 × 840 length, width and height respectively and the angle iron used is of dimensions 50 × 50 × 5.

(ii) The Shaft**:** The shaft is of dimensions 25mm dia. and length of 1200mm

(iii) The screen**:** The screen is of dimensions 2mm × 2mm aperture and was bent along side with the circumference of the concave cover.

From the literature, the bulk density of cassava mash was found to be 709 kg/m^3.Therefore, the weight of cassava mash that will fill-up the screen is given as;

$W_g = V_S \ J_g$ g (1)

Where;

W_g = weight of the *cassava in* N;

V_S = volume of the screen in m^3; = 0.00001238m^3

Jg = bulk density of *cassava* mash, Kg/m^3; and

g = acceleration due to gravity, m/s^2.

Therefore, W_g = 0.00001238 × 709 × 9.8

W_g = 0.086N

a. Shaft design

A shaft is a rotating machine element which is used to transmit power from one location to another. The power is transmitted by some tangential force and the resultant torque (or twisting moment) set up within the shaft permits the power to be transmitted to various machine or its elements linked up to the shaft. The shaft was designed to be a solid shaft and the material selected was mild steel. In order to transfer the power from the shaft, the various member such as pulleys, bearings, etc. are mounted on it. These members along with the force exerted upon them causes the shaft to bend. Therefore the shaft in this case is exposed to bending moment and torsional stress, since it is utilized for torque transmission and bending moment.

The design of the shaft is subjected to both twisting and bending moments. The shaft was supported by bearings at both ends and therefore, this allows the shaft to pass through the center of the sifting drum.

The power delivered by a shaft is given by;

P = F × V (Shigley and Mischke,2001).

where;

p = power (Nms per -1),

F = Force of sifting (N)

and V = velocity (m/s).

Total weight of the sifting system acting on the shaft is therefore;

weight of the sifting brush + weight of the lump breaking rod + weight of the rods carrying the sifting brush.

b. Determination of torque and bending moment

$$\mathbf{M_t} = \frac{60\,P}{2\pi N} \quad (2)$$

M_t = torque Nm

N = speed rev/min

P = power (which is the electric motor power 1.815kw or 2hp) KW

The total resultant components of the horizontal and vertical bending moments can be calculated using the formulae below;

$$M_b = \sqrt{(Mv)^2 + (Mh)^2} \quad (3)$$

Where; $\mathbf{M_b}$ = resultant bending moment

$\mathbf{M_v}$ = bending moment at the vertical loading

$\mathbf{M_h}$ = bending moment at the horizontal loading

c. Determination of the diameter of the shaft

To calculate the diameter of the shaft, the formulae Stated below can be used;

$$d^3 = \frac{16}{\pi Ss}\sqrt{(Kb\ Mb)2 \ + \ (K\ t\ Mt)2} \quad \text{(Khurmi and Gupta, 2004)} \qquad (4)$$

Where;

d= diameter of the shaft in mm

K_b= combined shock and fatigue factor to bending moment

M_b = maximum bending moment in Nm

K_t= combined shock and fatigue factor for spiral moment

M_t= maximum torsional Moment in Nm

S_s= Allowable Shear Stress; and

S_s = 40MN/m^3

d. Design of hopper

the volume of the hopper was calculated as;

$$V = \frac{h}{3}\left(A_1 + A_2 + \sqrt{(A_1 \times\ A_2)}\right) \quad \text{(Khurmi and Gupta,2004)} \qquad (5)$$

Where;

V = Volume of the hopper,m^3

A_1 = area of the top,m^3

A_2 = area of the base,m^3

h =height of the hopper =0.208m

The volume of the hopper was estimated to be 1.46×10^{-5} m^3

e. Pulley design

The ratio between the velocities of the electric motor pulley / driven pulley and the driven may be expressed mathematically as discussed below. let"

D_e = Diameter of the driver pulley

D_d = Diameter of the driven pulley

N_e = Speed of the driver in r.p.m

N_d = speed of the driven in r.p.m

Length of the belt that passes over the driver in one minute = $\pi D_e N_e$

similarly, length of the belt that passes over the follower in one minute = $\pi D_d N_d$

Since the length of belt that passes over the driver in one minute is minute is equal to the length of belt that passes over the follower in one minute, therefore (Balogun, 2006)

$DeN_e = D_d N_e$

Therefore, $N_d = \frac{D_e N_e}{D_d}$

f. Design calculation for belt and pulley

In order to compute the length of the belt required, we use the formula below.

$$L = \pi\,(R + r\,) + \frac{R-r}{C} + 2C \qquad (6)$$

where;

R = radius of the pulley on the driven shaft

r = radius of the pulley on the motor shaft
C = Center distance between the two pulley
L = Length of belt required
r = 47mm, R =76mm, C = 760mm
L = π (760 + 47) + (760 - 47)/ 760 +2 (760)
L =368.4 + 0.038 + 1520
L =1906.4m

g. Determination of belt tension
Considering a coefficient of U = 0.30 between the belt (rubber) & pulley (mild steel), and a groove angle $\theta = 40^0$ for v-groove belt
At high speed
$T_1 - T_c / T_2 - T_c = e^{u\theta}$ cosecβ
T_1 =Tension on the tight side of the belt in (N)
T_2 = Tension on the slack side of the belt in (N)
T_c = centrifugal tension (N)
$T_1 = T_c$ and $T_2 - T_c$ are the effective belt tension
$\beta = \theta/ 2 = 40/2 = 20^0$
Tc = mv2
v =2πrN/60 =2π × 0.047 × 1910/ 60
= 9.40m/s

h. Power design
The power required for sifting depends on the weight of the cassava mash; the sieving unit; velocity required to drive the shaft and the friction at the bearings. The friction produced by the bearings are negligible, because well lubricated ball bearings were used for the driving of the shaft. Therefore, the power required by this machine is assumed to depend on the weight of the cassava mash and the velocity of driving the shaft.
The power p, in kW required to operate the machine was estimated using;

$P = Ww^3r^2$ (Balogun, 2006).

$$P = \left(\frac{2\pi N^3}{60}\right) r^2 \quad (7)$$

where
M = mass of the pulley, kg
W = angular velocity,
R = radius of the pulley
N = number of revolution per minute
P = power
Therefore, 1.815kw (2hp) electric motor was selected for driving the machine

i. Pulley belt contact angle
The pulley belt contact angle θ was evaluated using the expression (Alabi, 2008)

$$\theta = 180 + D_1 - \frac{D_2}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \quad (8)$$

where;
D_1 and D_2 are motor and machine pulley diameter.

2.5 Machine Performance Evaluation

The machine was tested at three different speeds of operation; 480, 700 and 900 respectively, using a 2 hp electric motor at 10 kg loading rate each time. The quantity of cassava mash (10 kg) was weighed on the balance and weight was recorded. This was poured into the sieving unit and properly spread out. The machine was operated until the cassava mash was completely sieved. The time taken was noted and recorded. Also, the sample collected (output) from the sieve and the sieved residue were weighed and recorded. This procedure was repeated for three different times. The performance criteria tested for, were; Sifting capacity (SC) and Sifting efficiency (SE).

(a) Sifting Capacity (SC): The sifting capacity is the rate at which the machine sieves in kilogram Per hour and this was calculated as;

$$SC = M/t \qquad (9)$$

Where;
SC = sifting capacity (kg/hr)
M = mass of cassava mash loaded into the sieve (kg)
t = time taken to complete the sifting (hr)

(b) Sifting Efficiency (SE): This is defined as the percentage mass of fine cassava mash separated after sifting and is calculated as;

$$SE = \frac{M - C}{M} \times 100 \qquad (10)$$

where;
SE = sifting efficiency
M = mass of cassava mash loaded into the sieve.
C = sieved residue.

3. Results and Discussion

The machine was tested at the varying speeds of 480, 700 and 900 rpm respectively. The performance evaluation was carried out using, dewatered cassava mash at 42% moisture content (wb). The raw result of the performance test is shown in Table 1.

From Table 1, the raw data collected during the performance evaluation of the machine is presented. It could be observed that, with increase in the speed of operation, from 480-900 rpm, the quantity of sifted cassava mash keep increasing from 6.40 – 8.78 kg. This also directly reduced the time taken for the sifting operation from 8.12 – 4.12 min. In Table 2, the determined performance criteria are presented. The table further shows that the speed of operation affected the sifting output of the cassava mash sifter. Both the input and output capacity of the machine increased as the machine speed increases, which also has a direct impact on the efficiency of the machine. Also at 480 rpm, the machine was 68.50% efficient, while at 700 and 900 rpm the efficiency were 69 and 92% respectively. If could be observed that the efficiency at 480 and 700 rmp speed of operation were closely similar in value (68.5 and 69% respectively). This shows that the effect of that speed range could not have significant difference on the efficiency of the machine.

From the summary of the performance evaluation as presented in Table 3, it has shown that the efficiency (SE) and sifting capacity (SC) of the machine were directly proportional to the speed of operation. The highest efficiency (92%) was recorded at 900 rpm speed of operation, while the duration also reduced drastically. Increase in speed increases the magnitude of both sifting capacity and sifting efficiency. The increase in sifting capacity with increase in speed was due to the fact that increase speed led to more sifting of the cassava mash by the machine, as the cassava mash particles moved faster through the screen apertures. The sample of the cassava mash before and after sifting with the residue is shown in Plate 1-3.

4. Conclusion: A motorized cassava mash sifting machine was developed and tested. Based on the results of the performance evaluation, it can be concluded that mechanical sifting of cassava mash can be done more conveniently than traditional method. The machine performed satisfactorily at 900 rpm, with 92% efficiency and 145.63kg/hr sifting capacity. The machine could further be tested at higher speed and reduced moisture content for its performance evaluation. The choice of locally available material for the construction of the machine makes it suitable for adoption in local cassava processing industry, and the estimated cost of production which was ₦82,500 should be affordable for local processor.

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Table 1: Data Collected during performance Evaluation of cassava mash sifting machine

Speed of operation (rpm)	Mash M.C (%w.b)	Loading rate (kg)	Sifted mash (kg)	Sifted residue (kg)	Time taken (min)
480	42	10	6.40	3.15	8.12
700	42	10	6.50	3.10	6.11
900	42	10	8.78	0.80	4.12

Note: Values represented average (mean) of three replication for each speed

Table 2: Result of Determined Performance Evaluation Criteria of Cassava Mash Sifting Machine

Speed rpm	Mash M.C (%w.b)	Loading rate (kg)	Sifted mash (kg)	Sifted Residue (kg)	Sifted Time (min)	Input capacity (Kg/hr)	Output capacity (Kg/hr)	Sifting efficiency (%)
480	42	10	6.40	3.15	8.12	73.89	47.29	68.5
700	42	10	6.50	3.10	6.11	98.19	63.83	69
900	42	10	8.78	0.80	4.12	145.63	127.86	92

Table 3: Summary of the Results of Performance Evaluation of the Machine Showing tested Criteria

Speed rpm	Loading rate (kg)	M.C (%w.b)	SC (kg/hr)	SE (%)
480	10	42	73.89	68.50
700	10	42	98.19	69.00
900	10	42	145.63	92

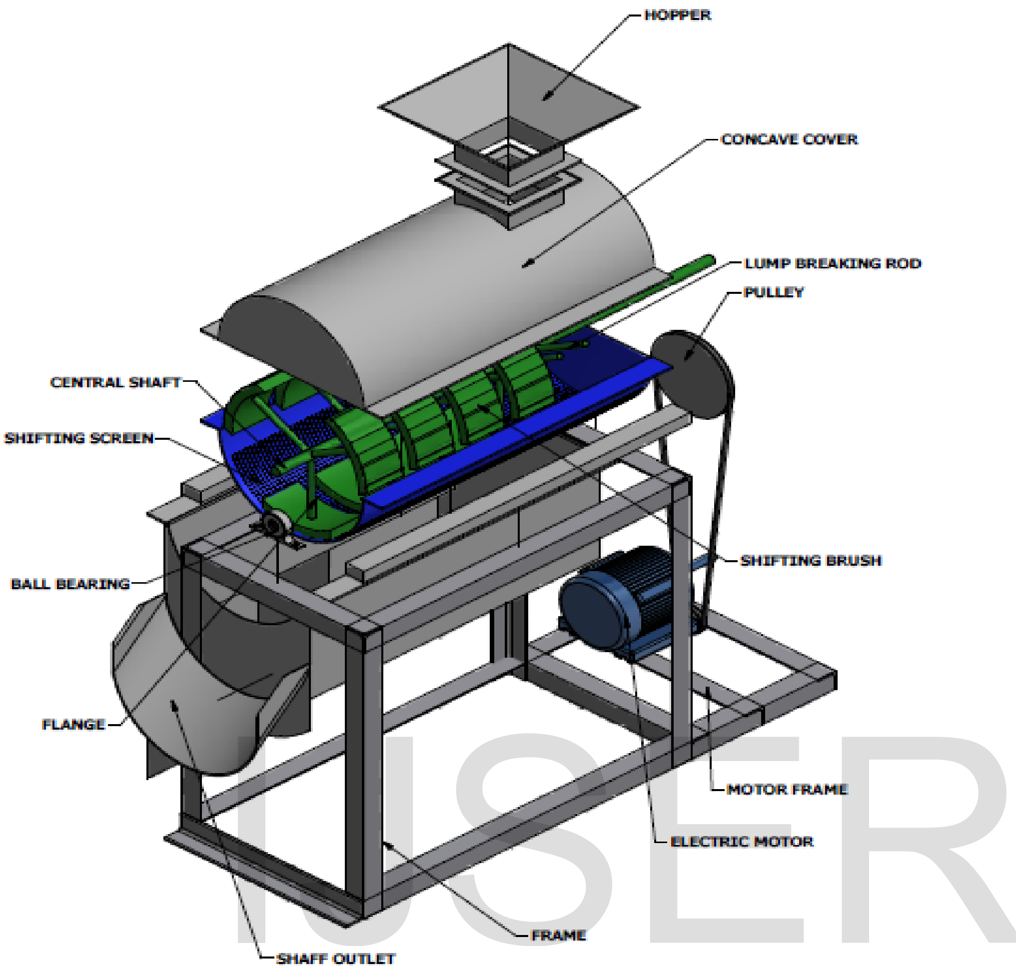

Fig. 3: Exploded View Of the Gari Sifting Machine

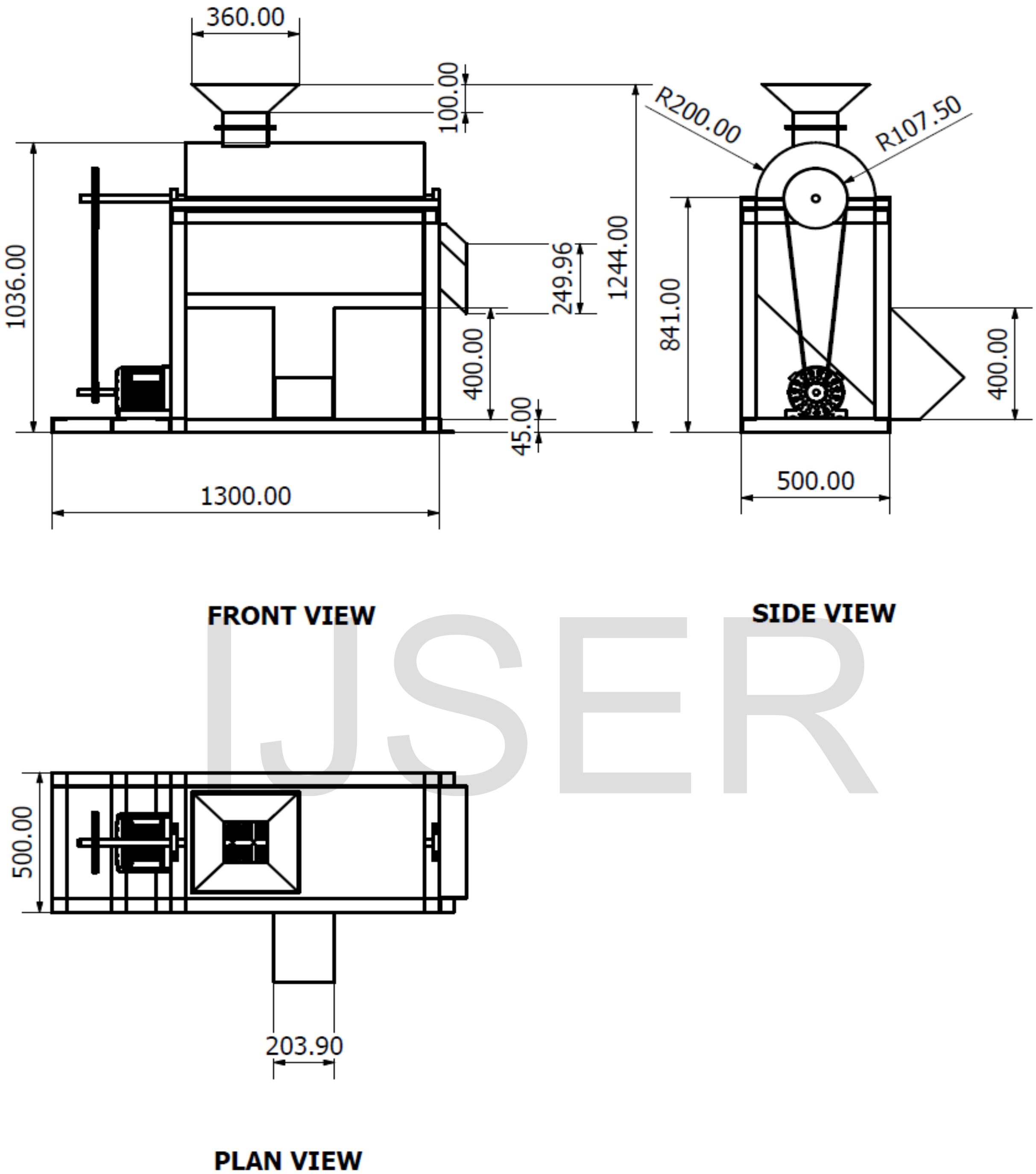

Fig.4 : Orthographic view of the gari sifting machine (dimensions in mm)

Plate 1: Sample of Cassava Mash before sifting

Plate 2: Sample of Sieved Cassava Mash

Plate 3: Sample Collected from the Sieved Residue Outlet