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Design of a Solar Powered Cassava Shredding Machine To Enhance Food Processing In Rural Areas

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Abstract
Manual processing of cassava tubers into its derivatives like tapioca, starch is tedious and time consuming, this drudgery has led to this study. The purpose of this study is to enhance agricultural performance via the design and fabrication of an improved cassava shredding machine that is capable of producing different sizes of cassava slices for further processing. The essence is to reduce processing time through increased surface area. This design produces different sizes for tapioca, ijapu, abacha, lafu and for other uses. The sizes range from 8-20mm in diameter. The machine consists essentially of a hopper where peeled cassava roots are put, beneath the hopper is the shredding plate with varied cutting blades coupled to a horizontal shaft which when in operation undergoes reciprocating motion. The horizontal shaft derives its motion through a slider crank mechanism coupled to an electric motor via a belt drive with a pulley for primary speed reduction and regulation. A rugged framework is provided for mounting of the machine and electric motor. The capacity of the machine is 150.2kg/hr. Maximum shredding efficiency of 96% was obtained with a shred aperture ranging from 5-12mm at a shredding speed of 1200rpm.

KEYWORDS: Rate Electricity Support Communities Performance Maintenance Women

I. INTRODUCTION

Cassava is an important crop that has great potential to support agricultural growth in Nigeria due to its wide range of uses, from human consumption to industrial applications (CMP, 2006). Africa produces 40-50% of the global cassava output (FAO, 2004) and Nigeria is the leading producer of cassava globally (Othman, 2011). Demand for cassava derivatives such as starch, garri (a type of processed cassava), tapioca, ijapu, lafu, etc, have increased immensely over the last two decades (Nweke, 2004). Therefore, there is a need for the design and fabrication of a shredding machine that will enhance the processing of cassava to its derivatives. Although, there are numerous designs of cassava shredding machines all over, little attention is given to solar energy as a source for powering processing machines in the country. Most machines produced are adapted to diesel engines or electricity from national grit which increases the cost of processing and maintenance. On the part of national grit; some rural communities are yet to be linked whilst others receive epileptic power supply, a situation that does not support regular production of these staple foods. Incidentally, most cassava derivatives are consumed daily in Nigeria as staple foods. Cassava shreds known within the eastern parts of Nigeria as Ighu, Nsisa, Ijapu or Abacha are local delicacies. It is made from peeled and shredded cassava roots, after steaming and fermentation for about 24hours (Tamuno, 2022). The product is then washed and eaten as a snack or made into a main meal or dried for storage. Hence, there is need for rural dwellers to process cassava without interruptions, but this is not the situation in the country. To overcome the above problem, it is imperative to have a system of constant supply of electricity to drive the processing machines.

An alternative source of energy is imperative for rural communities to meet up with timelines and reduce wastage of products due to spoilage, because there are no adequate storage facilities to cope with the production level, (Igoni & Harry, 2017). The Niger Delta part of Nigeria is a difficult terrain for major construction as such, a vast majority of her communities which this work considered are disproportionately disadvantaged when it comes to access to electricity. The option of renewable energy, therefore has a particular advantage in rural areas, where the cost of extending grid electricity will otherwise be challenging. Hence, two forms of renewable energy sources (solar and wind) were put into considered for this design, but solar energy has advantage over wind, because the terrain is about 5^0N of the equator with intense sunshine, whereas, apart from the coastal areas, wind seems to fluctuate immensely. Hence, solar energy as a renewable source stands out for this region.

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Solar energy is considered due to the numerous advantages derivable from its usage in rural communities. Some of these advantages are:

i. Wider areas for its installation
ii. It eliminates the problem of poor maintenance culture plaguing our society
iii. Donor agencies and philanthropies can take advantage and support rural women mostly engaged in cassava processing centres ones without repeated engagements
iv. There is no running cost, which eliminates contributions from users
v. It does not require local authorities to support with fueling from time to time after installation
vi. No pollution to the environment
vii. It takes quite a minimum of 3-5yrs before maintenance or replacement of batteries

II. MATERIALS AND METHODS

2.1: Materials

The unique thing about this machine is that all materials except the solar panels were locally sourced, the cutting drum and hopper are made of stainless steel, frame and stand are made of mild steel while the collector is an aluminum trough. All areas that will be in contact with the cassava are made of stainless-steel inline world health organization (WHO) standard for food processing materials. Other materials used are electric motor as a drive, aluminum pulleys, treated steel driving shaft, bearings, and the horizontal shredding plate made of stainless steel.

2.2: Design Consideration

The basic considerations are:

i. Strength, rigidity and simplicity of frame and support materials to absorb vibration
ii. Availability, ease of machining and cost of materials
iii. The machine is designed in modules, such that a component failure easily be replaced
iv. Accommodates different speeds of operation
v. Accommodates different sizes of cassava tubers available
vi. Cutters made of different sizes and are removable and replaceable

2.3: Components Design

2.3.1: Hopper

The hopper has a trapezium shape. It designed to accommodate a minimum of 20Kg per batch.

Preliminary adjustment gives the following dimensions:

Perpendicular Height of hopper = 0.5m

Length of top and base = 0.80m and 0.50m respectively

Width of top and base = 0.85m and 0.60m respectively

Area of base, A = 0.5 x 0.6 = 0.30m^2

Volume, V, is calculated based on the average area of top and bottom multiplied by the height, which gives:

Volume, V = $\frac{1}{3}$x area of base x H = 0.10m^3

2.3.2: V–Belt Selection

$$L = n(r_1 + r_2) + 2c\frac{(r_1+r_2)^2}{c} \quad (1)$$

Where; L is total length of the belt in mm,

Or

$$L = \frac{\pi}{2}(D_S + D_m) + 2C + \frac{(D_S - D_m)^2}{4c} \quad (2)$$

Where:

C = Centre distance between pulleys = 1000mm

D_S= Diameter shaft pulley = 360mm

D_m= Diameter of motor pulley = 150mm

Substituting values, we obtain the V-belt length as;

L = 2.34m

2.2.2: Shaft Design: using Von Mises equation

$$d = [\frac{16}{\pi s}(\sqrt{(K_b M_b)^2 + K_t M_t)^2})]^{1/3} \quad (3)$$

Where, M_b =maximum bending moment on shaft (1800Nmm)

M_t = maximum torsional moment on shaft (2540Nmm)

S = allowable shear stress for steel (480N/mm^2)

K_t, K_b = fatigue and shock factor for torsion and bending moments (1.5 and1.0).

The following values were obtained for shaft diameter, 27.8mm, 24.6mm and 20.01mm. For the purposes of this design 25mm shaft was adopted considering optimum efficiency and availability

2.2.3: Bearing Selection

Using SKF standard bearing selection chart for an internal diameter of 25mm for the shaft, the following values were obtained, outer diameter = 47mm, width = 12mm, and the bearing number is 6005 for the 6000 series Metric Bearings.

2.2.4: Base Frame Design

The base frame was designed using simply supported beam approach with a concentrated load at the centre with reactions at the two edges. Each edge is further divided into two support system, which are the columns. The following contributed to the concentrated load for the design:

i. cassava content 20.00Kg
ii. Peeling drum 5.20Kg
iii. Shaft 5.45Kg
iv. Outer cover plate 11.85Kg
v. Handle, upper support, bolts and nuts are taken as 10% of above load = 4.50Kg
vi. Cutter unit 2.40Kg

total load for design = 49.4 0x 9.81 = 484.614N. using a factor of safety of 2.5, because most rural women who are to handle this machine are illiterate and may not have the patient to read or asked someone to read and adhere to manufacturer's instructions. Thus, it factored into the design. Therefore, the design load becomes 1.214KN. Based on design analysis 3.18mm thickness was achieved, but 3.50mm angle iron was used for the support frame.

2.2.5: Cutter Design

The cutter is designed to have grooves at intervals to brush the cassava to produce abacha or tapioca or ijapu as the case may be. Each of this product is acceptable by design. See details on
drawing in appendix

2.2.6: Power Requirement

Power, P = $\frac{W}{t}$

Since, Torque = Force x shaft radius

Torque, T = 1214 × 0.0125 = 15.175Nm

Power = Torque x angular velocity

= 15.175 x 157.08 = 2,383.689W = 2.383KW

In terms of horse power, 2.383.7KW = 3.178hp. Therefore, 3.50hp system is used.

2.3: Solar Panel/Inverter Unit Specification

According Ginjah *et al* (2019), to obtain maximum efficiency from solar radiation, the power developed is computed from following equation;

$$P_{pv} = \eta_{pv} \times A_{pv} \times G_t \quad (4)$$

In Eqn (4), η_{pv} is efficiency, A_{pv} represents area of panel, and $G_{t\ optimum}$ tilt irradiance

Substituting the design power of 3.5KVA results in 10 panels. The actual power requirement from the design is 2.491Kw, which could be handled with 2.5KVA, but to compensate for loss a 3.5KVA is used.

III. DESCRIPTION OF MACHINE

The major components of the machine are the hopper (1), cutting unit (15), handle (5), electric motor (2), and base frame (3). When cassava is poured into the hopper, the handle with a plate introduces the feed force without which no cutting with take place. The hopper is deliberately designed slanted to intersect at 30^0 to the cutter direction. The cutter makes a slider motion while the shaft rotates, completing the slider-crank motion of a four-bar linkage. The base frame gives support and rigidity during operation to reduce vibration. The driving system is a belt and pulley system run by an electric motor.

IV. RESULTS AND DISCUSSIONS

4.1: Results

The results were presented here in two categories, the performance evaluation and the comparative cost analysis of operation of the machine.

4.1.1: Performance Evaluation of the Machine

The analysis was based on three factors; the quantity of cassava shredded in a given time interval, time taken for each quantity, and quantity successfully shredded. The values are presented in Table 1

Table 1: Experimental Results from Machine Evaluation

S/N	Initial Wt(Kg)	Final Wt (Kg)	ΔWt(Kg)	Time(min)	Throughput, Kg/hr	Efficiency
1	5	4.83	0.17	2.0	144.9	96.6
2	7	6.70	0.03	2.5	160.8	95.71
3	10	9.87	0.13	3.8	157.89	98.70
4	12	11.85	0.15	4.8	150	98.75
5	15	14.77	0.23	6.9	147.5	98.47
6	18	17.75	0.25	7.2	144	98.61
7	20	19.50	0/50	8.2	146.34	97.80

From the values obtained, the average value of the throughput capacity is 150.2Kg/hr. It is also observed that the value increased to a maximum of 160Kg/hr between 7-10Kg and gradually reduced about 145Kg/hr between 18-20Kg. from table 1, the efficiency is highest at 12Kg, whereas the throughput capacity is highest at 7.0Kg.

The chart in Fig. 1, is a chart showing the different masses of cassava that were shredded at different times with the attendant initial and final mass of product obtained.

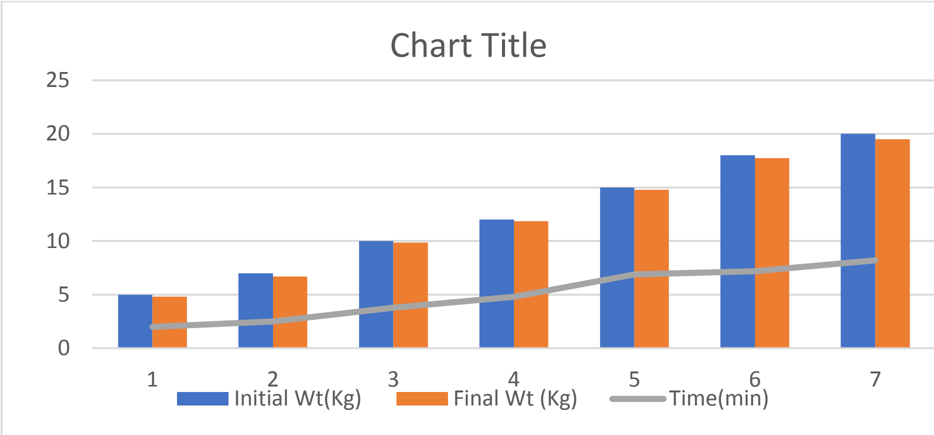

Fig 1: Shredding Rate of Cassava at Various Loads

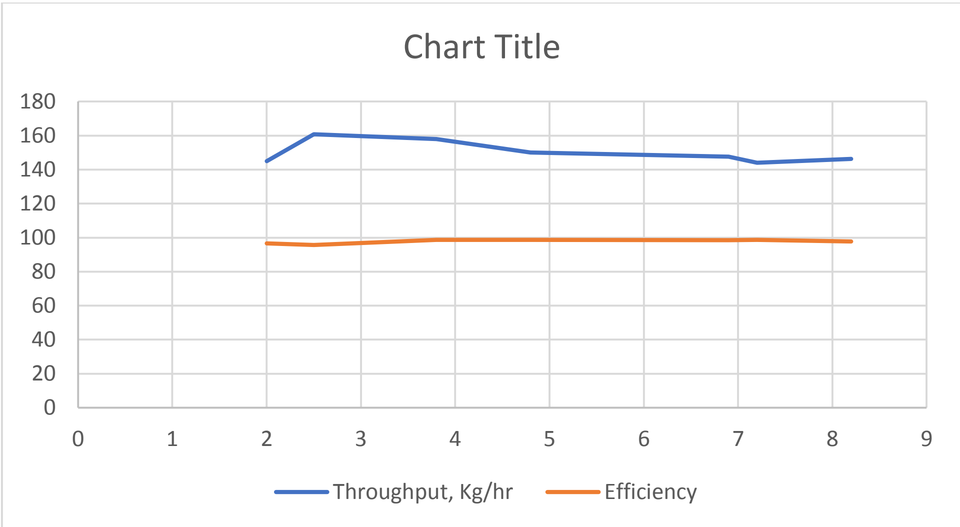

Fig 2: Relationship Between Throughput Capacity and Efficiency of Machine

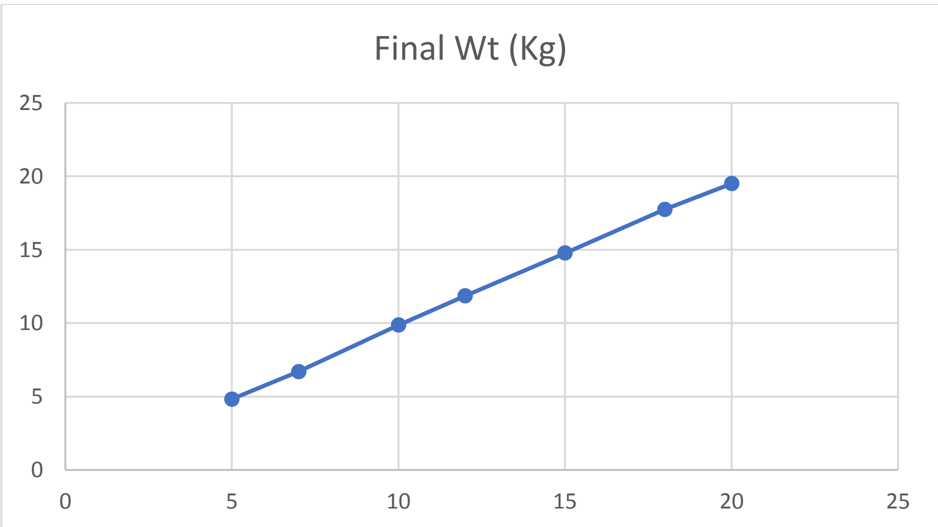

Fig 3: Relationship Between Initial and Final Load of the Shredding Process

4.1.2: Comparative Cost Analysis of Operation

The design was subjected to some preliminary running cost by the conventional method using generator and compared to using a solar powered system. The essence is to inform stakeholders to make appropriate choice of operating the shredding machine, because the machine can be operated with either of the arrangement. It could be run by a solar powered system using photovoltaic panels and an inverter system or a generator using diesel or petrol. The installation and three(3yrs) years running cost based on current market values are presented below. The figures below were obtained taking records for about three months and the rest were projected after discussions with commercial operators of cassava shredding machine in rural communities

This design is based on an output power of 2.80 - 3.00KVA.

Initial cost of generator (3.5KVA) = ₦650,000.00

Table 2. One Year Operational Cost of Using Generator to Run the Machine

S/N	ITEM/SERVICE	QTY	FUEL COST (₦)			MAINT COST (₦)	
			Daily	Monthly	Yearly	Monthly	Yearly
1	Fueling	12L	12,720	305,280	3,968,640		
2	Plugs Replacement	1		3,000	36,000		
3	Oil service	1.5L		3000	36,000		
	General Repairs					7,000	84,000
	Total				**3,968,640**		**84,000**
	Grand Total						**4,774,640**

Table 3. Second Year Operational Cost of Using Generator to Run the Machine

S/N	ITEM/SERVICE	QTY	FUEL COST (₦)			MAINT COST (₦)	
			Daily	Monthly	Yearly	Monthly	Yearly
1	Fueling	12L	14,400	345,600	4,147,200		
2	Plugs Replacement	1		4,000	48,000		
3	Oil service	1.5L		4,000	48,000		
	General Repairs					10,000	120,000
	Total				**4,243,200**		**120,000**
	Grand Total						**4,243,200**

The total cost estimate for 2yrs operation = ₦9,017,840.00

Considering inflationary trend of my country Nigeria, we adopted 15% increase from the first year giving rise to **₦4,743,336.00**

The installation cost of a 3.5KVA inverter with solar panel with two battery is **₦2,425,000.00**. the breakdown is shown in Table 4.

From tables 1 and 2, we can obtain a quarterly running cost of generator for the shredding unit as against a photovoltaic solar panel cost for two years. Since photovoltaic panels have no maintenance cost for a minimum of two years the cost remains the same for the period.

Table 4: Comparative Quarterly Operational Cost Estimate of Cassava Shredding Machine

S/N	Quarter	Running cost Per System	
	Quarters	**Inverter**	**Generator**
1	At installation	2,425,000	650,000
2	First	2,425,000	1,193,660
3	Second	2,425,000	2,387,320
4	Third	2,425,000	3,580,980
5	Fourth	2,425,000	4,774,640
6	Fifth	2,425,000	5,835,440
7	Sixth	2,425,000	6,896,240
8	Seventh	2,425,000	7,957,040
9	Eighth	2,425,000	9,017,840
10	Nineth	2,825,000	10,078,640
11	Tenth	2,825,000	11,139,440

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12	eleventh	2,825,000	12,200,240
13	Twelfth	2,825,000	13,261,040
14	Thirteenth	3,710,000	14,321,840

Table 4: Cost Estimate for the Installation of Solar Panels, Inverter and Batteries

S/N	ITEMS	QUANTITY	UNIT PRICE (₦)	SUBTOTAL (₦)
1	3.5KVA inverter	1	455,000	455,000
2	220AH battery	2	295,000	590,000
3	Solar Panel	10	82,000	656,000
4	Bypass switch	1	10,500	10,500
5	Solar charge controller	1	275,000	275,000
6	DC cables (6mm)	18yrds	6,000	108,000
7	Solar aluminum profile	3	16,000	48,000
8	Trucking pipe	2	2,500	5,000
9	Installation tape	2	400	800
10	4mm wire	10yrds	1,200	12,000
11	Concrete nails	1 pack	1,500	1,500
12	Screw and fisher	several	1.000	1,000
13	Roof Patch	2 yards	2,000	4,000
14	AC circuit breaker	1	7,000	7,000
15	DC circuit breaker	1	12,000	12,000
16	AC surge protector	1	25,000	25,000
17	DC surge protector	1	25,000	25,000
18	Breaker box	2	5,000	10,000
19	Battery rack	1	45,000	45,000
20	Scaffold	1	15,000	15,000
21	logistics			25,000
22	Service charge			95,000
	Total			**2,425,000**

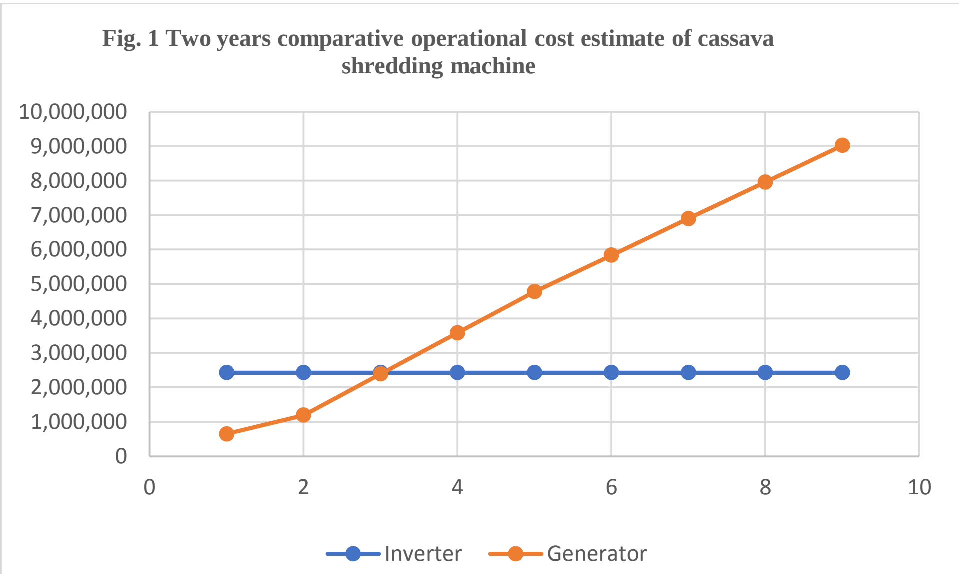

Fig. 4: Two Years Comparative Operational Cost Estimate of Cassava Shredding Machine

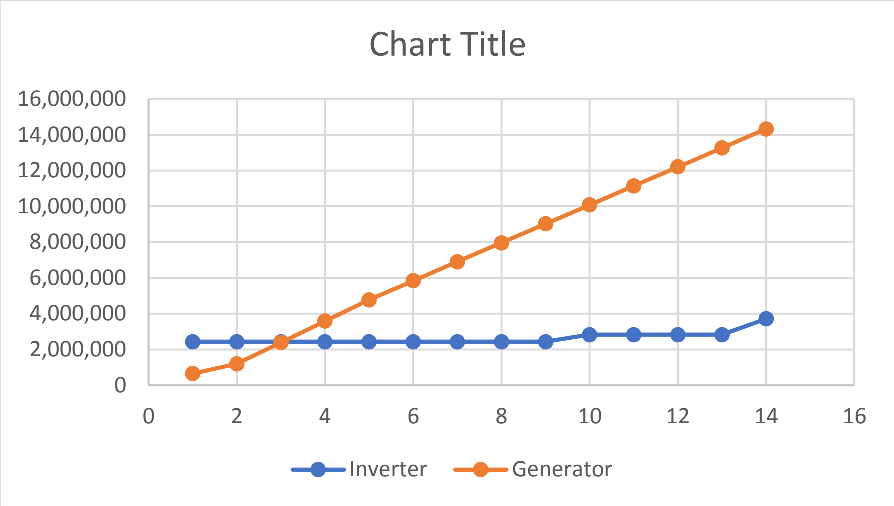

Fig.5: Three Years Comparative Operational Cost Estimate of Cassava Shredding Machine

4.2: Discussions

From Fig. 2, the throughput capacity had a sharp in rise in value and then gradually drop to a stable value of about 146.7Kg/hr, but the average value remains at 150.2Kg/hr.

In Fig. 3, it can be deduced that there is a straight-line plot between the initial weight of cassava as against the weight of cassava shredded, which has its interception on the origin.

Table 4 is an extract from a quotation to install a solar panel and inverter for a 3.5KVA power generation in a rural community. It is based current market prices Fig. 4 above shows the comparative cost of running the system in two years clearly showing the advantage in terms of cost in using solar inverter system. Over ₦6.5m will be saved in just 2yrs, making this choice more attractive to most organization. Besides, the use of photovoltaic-inverter reduces frequent maintenance problems. Although, a new generator may only require routine maintenance, but for one put into public use, there may be minor maintenance issues within 2yr. There is a slight increase in the cost of inverter usage in the third year due some maintenance on the batteries and solar panels as shown in Fig. 5, but on the overall, the difference still increased to ₦10m

V. CONCLUSION

A simple cassava shredding machine was designed with dual arrangement to drive the machine, either using generator or a combination of photovoltaic solar panels and inverters. The evaluation shows that the throughput capacity of the machine is 150.2Kg/hr, with an efficiency of 98.75 as its maximum at 12Kg whereas the maximum throughput capacity is at 7Kg, at 160Kg/hr. It also showed the advantage of using solar which is enormous. The system will save as much as ₦6.5m in 2yrs and ₦10m in 3yrs.

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APPENDIX

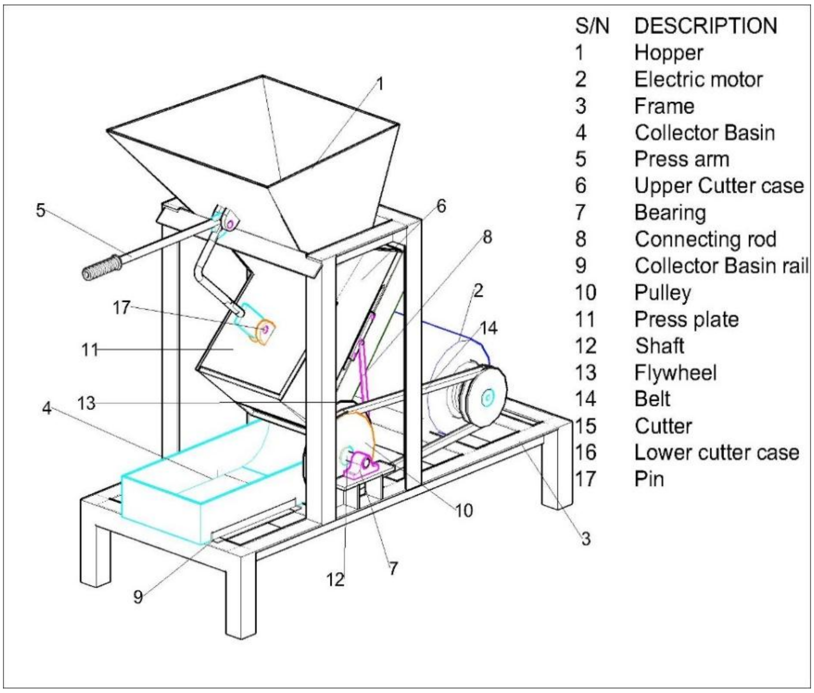

Fig 3: Assembly Drawing of Cassava Shredding Machine

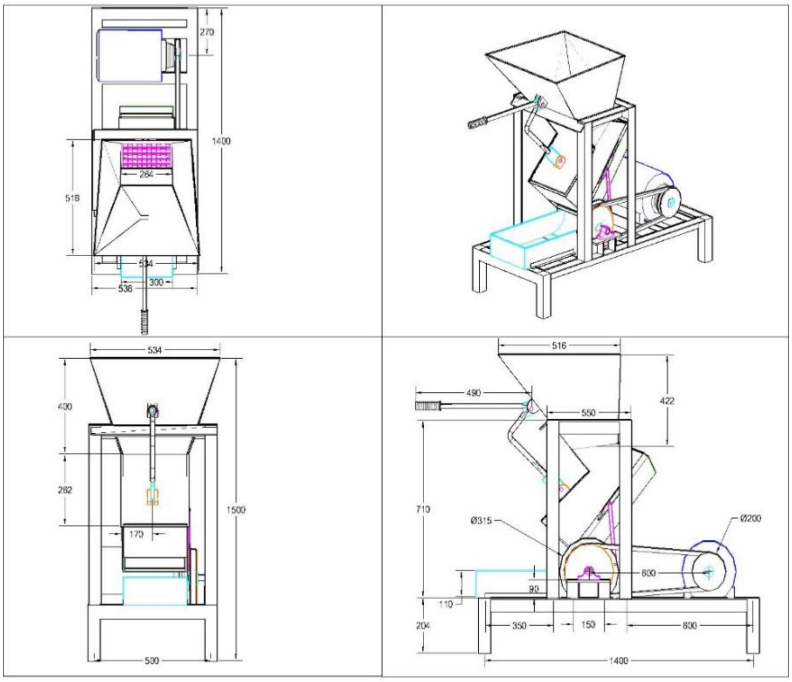

Fig 4: Orthographic Views of Cassava Shredding Machine