World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

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Design, fabrication and performance evaluation of a solar powered cassava grater

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World Journal of Advanced Research and Reviews, 2023, 20(01), 310–319

Publication history: Received on 22 August 2023; revised on 28 September 2023; accepted on 01 October 2023

Article DOI: https://doi.org/10.30574/wjarr.2023.20.1.2013

Abstract

This study evaluated some performance indicators of a solar powered cassava grating machine. The designing and fabrication of a prototype solar cassava grating machine was carried out using components that included food grade metal sheet metal bar, wooden roller/ grater encasing, pulley, belt, bolts, nuts. The fabricated grater was then connected via a pulley, roller, belt connection to a 1 horsepower rated Ac motor connected to a solar powering system. The solar powering system comprised of components such as 4units of solar panels (235wats), 1unit of charge controller (50 amp), 1unit of inverter (3.5Kva), and 2units of 200Amh rated batteries in series connection. Also, a mass of cassava weighing 100kg was grated in batches using the solar powered cassava grater and the grating time was determined to be 14.90mins (0.25hr). The value was significantly lower than that obtained from grating the same quantity of cassava roots on the combustion engine powered cassava grater (conventional grater) of similar specification which recorded a grating time of 17.60mins. (0.27hr). Values, obtained for some performance indicators, showed a grating efficiency and rate of 96.16% and 0.0025hr/kg respectively. Also, the throughput capacity was determined to be 400.00kg/hr. while power consideration yielded 0.0019kwh/kg for each kg of cassava roots grated. The result showed an overall improvement in all performance indices evaluated which is indicative of improvement in the efficiency.

Keywords: Design; Fabrication; Cassava; Grater and Evaluation

1. Introduction

The research explores the use of an inexpensive and clean (ecofriendly) solar energy to power and drive the grating unit in the processing chain of cassava roots.

Cassava *Manihot esculenta* is one of the most important food crops that is widely cultivated and consumed in the tropics including Nigeria, where it is variously processed into different forms before consumption. Cassava is a highly perishable root crop, storing not more than few days and therefore, immediate processing of cassava roots soon after harvest is usually carried out, to extend its shelf life and also reduce the toxic cyanogenic glucoside content to a safe level, [1].

The processing chain of cassava roots most times is a capital and labor intensive process and involve many operations that maybe mechanized or manually carried out. In the rural areas of Nigeria, cassava processing maybe mechanized or manually carried out or still a combination of both, [4]. Most times, the power source employed to drive the mechanized processing of cassava is usually from combustible engines (premium motor spirit and diesel engines) which contribute to cost of operation, low output and environmental pollution.

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Also a cleaner source of power generation is possible by harnessing the solar energy from the sun using the solar powering unit comprising of components such as solar panels, charge controller, inverter, batteries and also Ac motor to deliver the power needed in driving some of the unit operations involved in cassava processing

1.1. Related work

Cassava *Manihot esculenta* is one of the most important food crops that is widely cultivated and consumed in Nigeria and many other West African countries. As a staple, it is variously processed into forms such as meals (eg garri, fufu, noodles and tapioca), flour, chips and starches. The meal and flour forms account for the bulk of cassava used for human food in the tropics, while cassava chips and starches find greater application in many industrial processes such as the pharmaceuticals and livestock feed production, [5].

Nutritionally, fresh cassava is primary source of carbohydrates and contains very little protein and fat. The roots contain significant amount of minerals such as phosphorus, iron and calcium and also relatively rich in vitamin C and contain traces of thiamine, riboflavin and vitamin A, [1].

Cassava as a root crop is highly perishable and can hardly store for more than three days at ambient, so that the usual practice among local farmers is, immediate processing of fresh roots soon after harvest. Cassava roots also contain cyanogenic glucoside whose concentration may be higher or lower than 100mg/kg, [2]. Processing of cassava of cassava roots therefore involves, transforming the highly perishable, toxic acid containing roots, into a stable form that is safe for consumption and can also store for extended period, [1]. Also the processing of cassava roots is still largely carried manually, in many rural parts of Nigeria.

However, many research projects have over the years, made considerable progress in mechanization of some unit operations involved in cassava processing, especially the use of combustible engines (premium motor spirit and diesel engines) in driving operations such as peeling, grating, dewatering, frying etc., [3].

The use of solar energy, to replace the combustion engines in powering and driving the grating unit in the processing chain of cassava roots is possible. This will provide the opportunity of creating machines capable of handling industrial scale cassava processing operations/increased output, also reduce environmental pollution and cost of operating and maintenance associated with combustion engines

2. Material and methods

This study was undertaken between the months July 2022 and March 2023 at the welding and Fabrication Workshop of the Mechanical Engineering Technology Department, Electrical Power and Simulation Lab of the Electrical/Electronic Engineering Technology Department and Wet Processing Workshop of the Food Technology Department, all in Akanu Ibiam Federal Polytechnic Unwana. The solar powering components including solar panels, charge controller, inverter, batteries and the materials such as mild steel, stainless steel alloy, rubber and cast iron used for fabrication of cassava grater were all procured from Onitsha Main Market, Onitsha, Anambra State, Nigeria.

2.1. Material selection

Material selection was carried out with considerations to the desired performance requirement. Materials such as mild steel, stainless steel alloy, rubber and cast iron were mostly used to fabricate the various components of the grating machine as they are able to withstand the varying forms and degrees of stresses, strains, torque and effects due to friction.

Table 1 Materials selection and specification/ dimensions for fabrication of cassava grater

Component	Material	Specification/ dimension
Frame (structural base)	Angle iron	55mm x 55mm
Plummer block	Cast Iron	Ø40mm
Bolts & Nuts	Mild steel (stainless)	M16 and M10
Hopper and discharge chute	Sheet of stainless steel	2mm
Drum	stainless disc	Ø300mm x400
Electric motor	Cast Iron	1.HP, 1450rpm
V belt	Polyester fibre	530mm
Pulley	Mild steel	9" and 3” pulleys
Shaft	Stainless shaft	Ø50mm x 600mm
Perforated sheet plate	Stainless sheet	2x200x400mm

2.2. Method

The following methods were applied in the design, fabricate and evaluate the solar powered cassava grater.

2.2.1. Designing/fabrication of cassava grater

In designing the solar powered cassava grater components, a 3D model drawing of the grater was produced using the engineering drawing package, SolidWorks 2019 application. Fabrication of the cassava grating machine components were carried out using food grade materials according to the project specifications outlined in table 1. Also fabricated components were assembled and mounted on a frame work. The machine was also connected via a pulley, roller, belt connection to 1 horsepower rated Ac motor (also on the frame work) capable of transmitting a torque of 4.94Nm and rotational motion of 1450rpm on the shaft for effective and efficient grating of cassava roots.

2.2.2. Assembling of solar powering unit

The solar powering unit comprising of the following components 4 solar panels (rated 235watts each), 1 charge controller (rated 50 amp), inverter (3.5Kva output) and 2 batteries of 200Amh capacity (in series connection) were assembled with the panels strategically placed to ensure maximum exposure to sunlight. The solar powering unit was then connected to the electric motor to deliver the power needed for driving the fabricated cassava grating machine.

2.2.3. Design considerations

The following calculations were employed in the Shaft Design of the solar powered cassava grating machine

Loads and stresses on shaft

$$W_p = \text{Mass of the pulley x acceleration due to gravity} \quad \ldots\ldots\ldots\ldots\ldots 1$$

Where mass of the pulley = 1.43kg and acceleration due to gravity is taking to be 9.8m/s^2

$$W_p = 1.43 \times 9.8 = 14.014N$$

$$W_D = \text{Density of the material x Volume of the drum x acceleration due to gravity} \quad \ldots\ldots\ldots\ldots\ldots 2$$

$$\text{Density of the material } (\rho m) = 7850 Kg/m^3, \ \ldots\ldots\ldots\ldots\ldots \ [3]$$
$$\text{Volume of the drum } (V_D) = \pi(R_d^2 - r_d^2)h_d \quad \ldots\ldots\ldots\ldots\ldots 3$$

Where $D_d = 296mm = 0.296m$, $R_d = 148mm = 0.148m$, $r_d = 20mm = 0.02m$;

$$h_d = 390mm = 0.39m, \text{ and } \pi = 3.142$$

$$V_D = 3.142(0.148^2 - 0.02^2) \times 0.39 = 2.64 \times 10^{-2} m^3$$

Also volume of the perforated sheet = $1.6 \times 10^{-4} m^3$

Distributed load on the shaft due to the drum $W_D = 7850 \times (2.64 \times 10^{-2} + 1.6 \times 10^{-4}) \times 9.8$

Therefore $W_D = 2043.26N$

Torque transmitted to the shaft (T_s)

$$\mathbf{T_s} = \frac{P_S}{\omega} = \frac{P_S \times 60}{2\pi N} \quad \text{……………4}$$

Electric motor power rating = 1hp = 750W or 0.75KW and 1450rpm

Therefore $T_s = \frac{750 \times 60}{2 \times 3.142 \times 1450} = 4.94Nm$

Permissible shear stress of the shaft (Ts)

$$\tau_s = \frac{Distributed\ load\ on\ the\ shaft}{Cross\ sectional\ area\ of\ shaft} \quad \text{……………..5}$$

Where cross sectional area of shaft $A_s = \frac{\pi D_S^2}{4}$ …………6

$$A_s = \frac{3.142 \times 0.049^2}{4} = 1.89 \times 10^{-3} m^2$$

Therefore $\tau_s = \frac{2043.26}{1.89 \times 10^{-3}} = 1.081 \times 10^6\ N/m^2 = 1.081 \times 10^6$ MPa

Twist moment (T_w) = $\frac{\pi \tau s D_S^3}{16}$ …………7

$$= \frac{3.142 \times 1.081 \times 10^6 \times 0.049^3}{16} = 399.60Nm$$

Bending stresses on the shaft

The grater shaft is subjected to bending stresses given as
Bending moment (M) = WD × Ld …………8

$$= 2043.26 \times 0.39 = 796.87Nm$$

Bending stress is given by $\sigma_b = \frac{M}{Z}$…………9

Where $Z = \frac{\pi}{32} \times D_S^3$,……………10

$$Z = \frac{3.142}{32} \times 0.049^3 = 1.16 \times 10^{-5}$$

Therefore $\sigma_b = \frac{796.87}{1.16 \times 10^{-5}} = 69MPa$

Speed transmitted to the shaft

The speed transmitted to the grater shaft $V_s = \frac{\pi N D_2}{60}$ …………11

Diameter of the shaft pulley D_1 = 8.4" or 8.4 × 0.0254 = 0.21336m

Diameter of the electric motor pulley D_2 = 2.8" or 2.8 × 0.0254 = 0.07112m

Where unit inches = 0.0254 meters

$$\text{Therefore } V_s = \frac{3.142 \times 1450 \times 0.07112}{60} = 5.40\ m/s$$

$$\text{Speed ratio} = \frac{D_1}{D_2} \quad \ldots\ldots\ldots\ldots\ldots 12$$

$$= \frac{8.4"}{2.8"} \text{ or } \frac{0.21336m}{0.07112m} = 3$$

Belt design (L_b)

The belt design is gotten the equation $L_b = \frac{\pi}{2}(D_1 + D_2) + 2X + \frac{(D_1 - D_2)^2}{4X}$ ……………13

$$\text{Where } X = \frac{D_1 + D_2}{2} \ldots\ldots\ldots\ldots\ldots 14$$

$$= \frac{0.21336 + 0.07112}{2} = 0.142\text{m or} \approx 5.59"$$

Therefore $L_b = \frac{3.142}{2}(0.21336 + 0.07112) + 2 \times 0.142 + \frac{(0.21336 - 0.07112)^2}{4 \times 0.142} = 0.767m \approx 0.77m$

The angle of contact on electric motor pulley (θ) $\sin \alpha = \frac{D_1 - D_2}{2X}$……………15

$$= \left(\frac{8.4 - 2.8}{2 \times 5.59}\right)" \text{ or } \left(\frac{0.21336 - 0.07112}{2 \times 0.142}\right) m = 0.5$$

$$\alpha = \sin^{-1}(0.5) = 30^{o}$$

$$\text{The angle of contact } \theta = 180 - 2(\alpha) \quad \ldots\ldots\ldots\ldots\ldots 16$$

$$= 180 - 2(30^{o}) = 120^{o} \text{ or } \left(\frac{\pi}{180} \times 120\right) rad = \frac{3.142}{180} \times 120 = 2.09\ rad$$

Hopper/ Bucket Design

$$\text{The volume of the hopper } (V_h) \text{ is given as } V_h = \frac{1}{2}(a + b) \times h \times H \quad \ldots\ldots\ldots\ldots\ldots 17$$

$$= \frac{1}{2}(34 + 39) \times 27 \times 40 = 39420\text{cm}^3 = 0.039$$

2.2.4. Operating of solar powered cassava grater

The solar powering unit was set up and allowed to charge (without any load) for 24 hours, for the initial charging of the batteries to their maximum capacity. The unit was also connected to the fabricated cassava grating machine via the electric motor, and the machine operated for some time to allow the speed to stabilize. Test-running of the solar powered cassava grating machine was carried by loading a given amount of previously peeled and washed cassava roots into the hopper and grated until finely grated cassava mass was obtained.

2.2.5. Evaluation of solar powered cassava grater

In evaluating the fabricated solar powering cassava grating machine, previously peeled and washed cassava roots of known weight, were introduced in batches into the machine via the hopper and grated. The grating process was continued until finely grated cassava mass was obtained (final output). The time taken to obtain the required grated cassava mass was noted and recorded. The whole process was also repeated for different weights of cassava and the respective time taken to obtain the required output in each case were noted and recorded. The production rate (with respect to time) of the solar powered cassava grating machine was compared with that of the combustible engine cassava grater of similar specification/capacity, using 100kg of cassava roots.

Also the fabricated solar powered cassava grating machine was subjected to various tests namely, performance evaluation, efficiency test, output, capacity and throughput determination following the design concepts of the research project. Also the results obtained were compared to those gotten from combustion engine powered cassava grating machine and the variations noted.

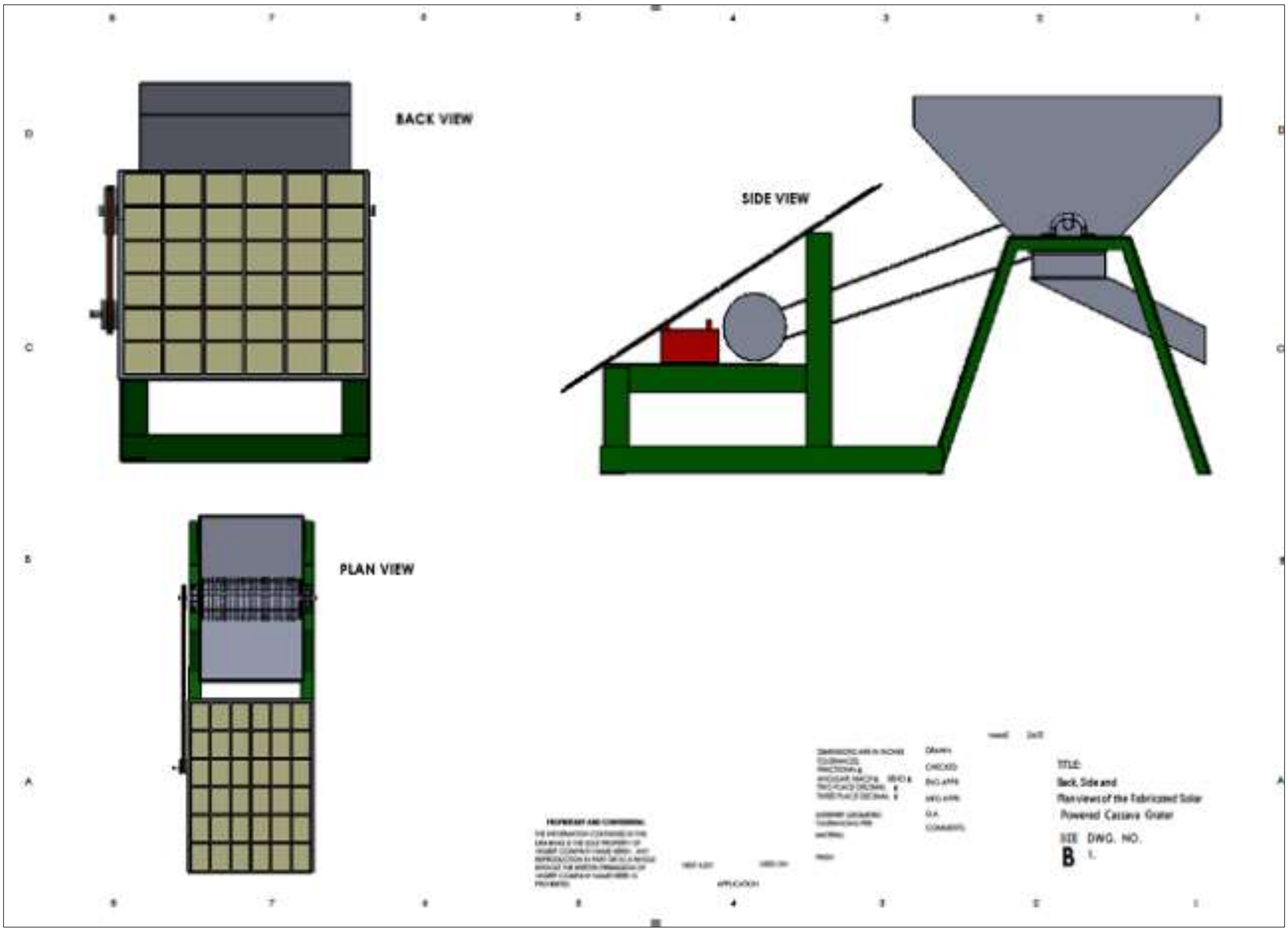

Figure 1 Back, Side and Plan views of the Fabricated Solar Powered Cassava Grater

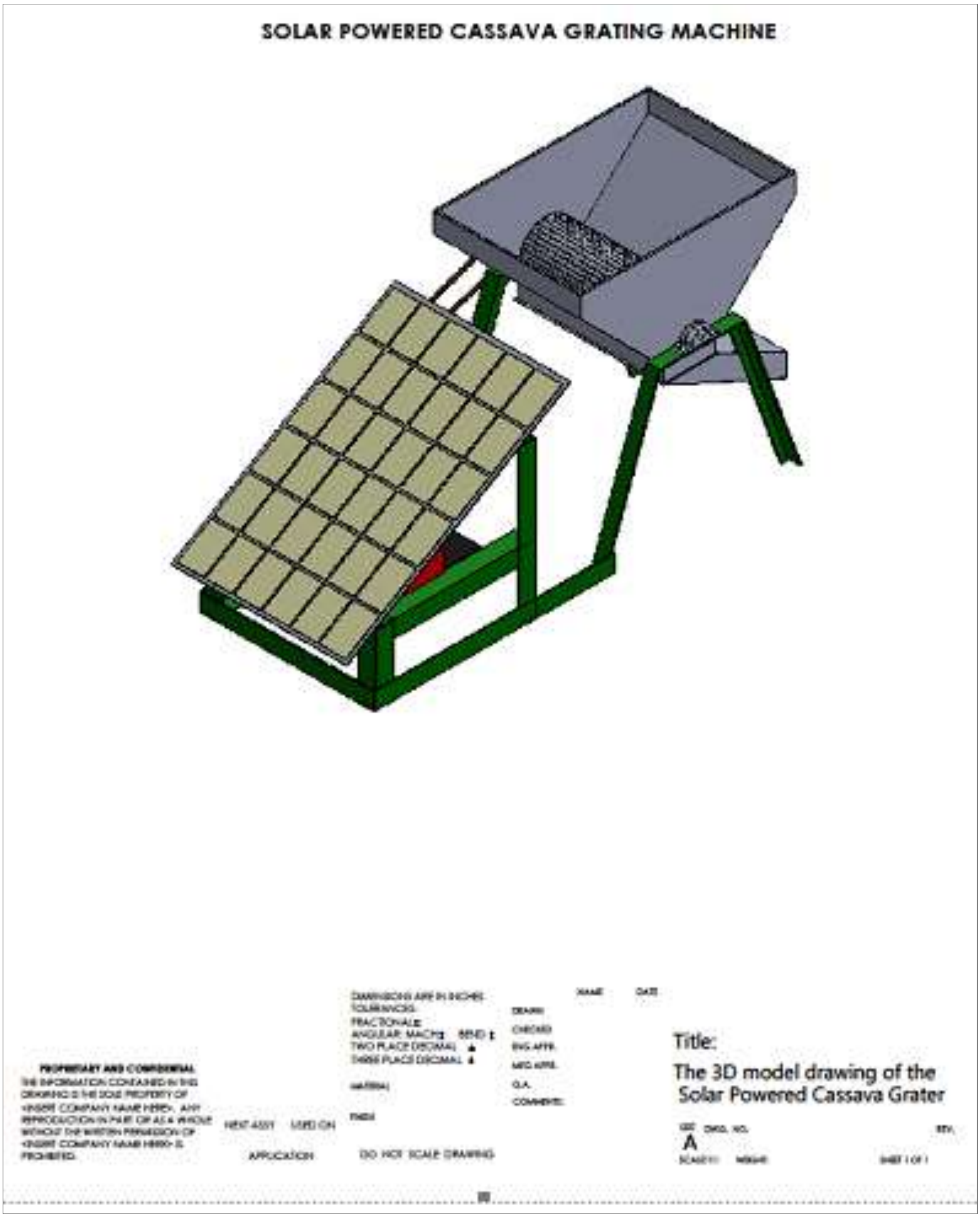

Figure 2 3D Model Drawing of the Solar Powered Cassava grater

3. Results

Figures 1 and 2 shows the Back, Side and Plan views and 3D model drawing respectively of the fabricated cassava grater. The machine drawings were produced using the engineering drawing package SolidWorks 2019 application software. Also tables 1 and 2 shows the materials selection and specification/ dimensions and weight of cassava batches (in kg) and grating time (in min.) respectively of the fabrication of cassava grater.

3.1. Performance evaluation

Performance evaluation of fabricated solar powered cassava greater was carried out to determine the production rate and the result also compared with that of the combustion engine powered cassava grater. A given weight of cassava roots (in kg) was grated in using the combustion engine powered grater and the time taken to completely grate the bulk was noted. The grating was done in batches and in each case, the weight of each batch loaded and the time taken to achieve complete grating were noted.

The whole process was repeated using the solar powered cassava grater using the same weight of cassava roots (in kg) and in each case, the weight of each batch loaded and the time taken to achieve complete grating were noted. Also, at the end of each grating operation, the resulting cassava pulp were separated into finely grated cassava pulp and coarsely/rough cassava pulp and their weight noted. The results are shown in Table 2.

Also the following mathematical operations was used to calculate the performance of solar powered cassava grating machine

3.1.1. Grating Efficiency

The grating efficiency of the solar powered cassava grating machine is calculated as follows

$$\text{Grating efficiency} = \frac{\text{Weight of uniformely grated cassa } (Kg)}{Weight\ of\ cassava\ roots(Kg)} x\ 100\%$$

$$= \frac{96.16\ (Kg)}{100\ (Kg)} x\ 100\% = 96.16\%$$

3.1.2. Grating Rate

From tab 2, weight of cassava roots = 100kg; time taken to completely grate the cassava bulk using the combustion engine powered grater = 17.60 min(0.29hr) time taken to completely grate the same amount of cassava roots using the solar powered grater =14.90 min (0.25hr);

Therefore grating rate of combustion engine powered grater = $\frac{Grating\ time\ (hr)}{Weight\ of\ cassava\ roots\ (kg)}$

$$= \frac{0.29hr}{100kg} = 0.0029hr/kg$$

while grating rate of solar powered grater = $\frac{Grating\ time\ (hr)}{Weight\ of\ cassava\ roots\ (kg)}$

$$= = \frac{0.25hr}{100kg} = 0.0025hr/$$

3.1.3. Throughput Capacity determination

From Table 2, the total quantity of cassava root batches loaded into the combustion engine powered grater (conventional grater) and solar powered grater were 100kg and also the total time required to completely grate the bulk were 17.60mins (0.29hr) and 14.90mins (0.25hr) respectively.

Therefore throughput capacity for the conventional grater= $\frac{input\ quantity\ (kg)}{Required\ working\ hour\ (hr)}$

$$= \frac{100}{0.29} = 344.83kg/hr.$$

Also the through put capacity of the solar powered cassava grater = $\frac{input\ quantity\ (kg)}{Required\ working\ hour\ (hr)}$

$$= \frac{100}{0.25} = 400.00kg/hr.$$

3.1.4. Power consideration

Given that electric motor power rating = 1hp = 750W or 0.75KW and grating time required for the solar powered grater to completely grate 100kg of cassava roots = 14.90mins (0.25hr)

Then 0.75kw x 0.24 = 0.1875kwh

Therefore, power consumption = $\frac{0.1875}{100}$ = 0.001875 ≈ 0.0019kwh/kg

Table 2 Weight of cassava batches (in kg) and grating time (in min.) using combustion engine powered grater and fabricated solar powered grater

S/N	Weight of Cassava batch (Kg)	Grating time (minutes)	
		Combustion engine powered grater	Solar powered grater
1	5.00	1.30	1.10
2	8.00	1.70	1.40
3	11.00	2.10	1.70
4	15.00	2.60	2.20
5	18.00	2.90	2.50
6	21.00	3.40	2.90
7	22.00	3.60	3.10
Total	100.00	17.60	14.90

4. Discussion

From Table 2, the total quantity of cassava roots batches loaded in the solar powered cassava grater was 100kg and the time required to completely grate the bulk (grating time) was 14.90mins (0.25hr). The value was significantly lower than that obtained from grating the same quantity of cassava roots on the combustion engine powered cassava grater (conventional grater) of similar specification which recorded a grating time of 17.60mins. (0.27hr).

Performance evaluation of the fabricated solar powered cassava grating machine produced considerable results in terms of grating efficiency, grating rate, output and throughput and also power consideration. Values obtained showed a grating efficiency and rate of 96.16% and 0.0025hr/kg respectively. Also, the throughput capacity was determined to be 400.00$kg/hr.$ while power consideration yielded 0.0019kwh/kg for each kg of cassava roots grated.

The result showed an overall improvement in all performance indices evaluated which is indicative of improvement in the production rate.

5. Conclusion

The design and fabrication of solar powered cassava grating machine was carried out with improved design specifications using a carefully selected materials and also with considerations to simplicity in assembling and dissembling, to achieve the stated objectives. Performance evaluation of the fabricated cassava grating machine produced considerable results in terms of grating efficiency, output and throughput and in comparison with the conventional combustion engine driven cassava grater, indicated an overall improvement in all performance indices evaluated. Therefore the use of solar energy, to replace the combustion engines in powering and driving the grating unit in the processing chain of cassava roots is effective in handling large scale cassava grating operations.

Compliance with ethical standards

Acknowledgments

The authors wish to acknowledge the sole sponsorship of this work, Tertiary Education Trust Fund towards the successful completion. Also the Akanu Ibiam Federal Polytechnic, Unwana Institute Based Research Committee for their effort.

Disclosure of conflict of interest

Authors have declared that no competing interests exist.

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