ISSN: 2456-3676

Development of Grating and Dewatering Units of a Cassava Processing Machine

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doi: 10.51505/IJAEMR.2022.7203 URL: http://dx.doi.org/10.51505/IJAEMR.2022.7203

Abstract

The cassava processing machine that combines two units' major operations of grating and dewatering was developed. The development of the machine prototype involved design, fabrication and performance evaluation. The machine which is simple to operate and maintain was powered by 2.2 kW (3.8 hP) single phase, electric motor. The machine was tested with five grater speeds (1100, 1200, 1300 1400 and 1500 rpm), dewatering with five speeds (150, 200, 250, 300, and 350 rpm) and five compression spring loads (100, 200, 300, 400 and 500 N). The recommended cassava variety TMS 30110 was also used. The results obtained from the performance of the machine showed a significant improvement over similar machines. The results from performance evaluation of the cassava processing machine showed that, 1400 rpm grater speed has the highest grating capacity and efficiency. Also in the combine machine (grating and dewatering) experiment, 1400 rpm grater speed, 300 rpm screw expeller speed and 400 N compression spring load has the highest machine capacity, throughput and efficiency of 114.23 kg/h, 95. 88 kg/h and 83.9% respectively from 10 kg cassava tuber. The moisture content 46% wb obtained was within the recommended value. The losses recorded during machine operation was minimal.

Keywords: Development, grating, dewatering, cassava, processing, machine

1. Introduction

Cassava (*Manihot esculenta*) is a crop which has high content in starch and is usually processed to edible form of foodstuff before consumption (Okoko *et al*., 2019. It is a crop with natural ability to grow under wide range of conditions (Burns *et al*., 2010). The root from which garri is produced, is rich in fiber, copper and magnesium (Ovat and Odey, 2018). Olukunle *et al*. (2005) also describe cassava as a wonder crop due to its potential uses in several agro and agro-allied

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ISSN: 2456-3676

industries. Since 1990, Nigeria has surpassed Brazil as the world's leading producer of cassava with an estimated annual production of 54 million tons from an estimated area of 3.4 million hectares of land (IITA- ICP, 2018). It is mainly grown in Latin America, Brazil, Nigeria, Sub-Sahara Africa, some Asia countries like China and Indonesia. Its drought tolerance and its ability to thrive in marginal soils has been widely acknowledged (Kolawole and Agbetoye, 2007) and this endears it to most farmers. Cassava production is high in Africa with 62% of total production in the world (Olutayo, 2014). Cassava is one of the widely grown consumable food crops in the southern and eastern parts of Nigeria. This is because it can be transformed from its raw form (tuber) to several finished products, which can serve as food for human consumption such as *garri, fufu*, *abacha,* cassava starch and cassava flour (Darlene *et al.*, 2019). Ethanol, which serves as biofuel can also be produced from cassava. The interest of this research is to develop a combine grating and dewatering units of a cassava processing machine.

2. Materials and Methods

2.1 Design considerations

The following factors were put into considerations in developing the model of the cassava grating and dewatering machine:

i. Safety of the operator and people around during operation were considered. The frame and other components of the machine were joined together using appropriate bolt and nut.
ii. The comfort of the operator was also put into consideration and the machine heights were at the breast level which removes the over stretching of the operator minimally.
iii. Ease of operation, assembling and disassembling of the machine for cleaning purpose.
iv. Materials availability are considered.
v. The overall weight and space of the machine was considered.
vi. The frame of the machine was made of angular iron of known thickness to ensure rigidity and still maintain lightness.
vii. Stainless steel was considered for the hopper and the dewatering chamber to prevent contamination and rusting.
viii. The speed of the machine was considered, as this will determine the optimum machine output and efficiency.
ix. Cost and affordability of materials were also put into consideration.

2.2 Design of Machine Components

The conception of the machine described is carried out using innovative ideas that were picked from several sketches. The final design was based on the knowledge of cassava processing factories visited, and also information obtained from literatures. The major components of the machine were: hopper, grating units, dewatering units, discharged units, transmission shaft and system, prime mover and frame.

2.2.1 Hopper

The hopper is a truncated rectangular pyramid which act as input unit. It is designed to provide smooth supply of cassava tubers to the grating unit.

Hopper inclination

$\alpha = tan^{-1}\mu$ (Kolawole, 2012) (1)

Where, α = angle of repose / inclination, μ = co-efficient of friction

μ = 0.680 for cassava mash / granular material (Kolawole, 2012)

$\alpha = 34.22^0$ but 45^0 was used.

Determination of the capacity of the hopper

The density of the stainless steel use is 8000 kg/ m^3 (www.dsstainless) this was determined using

$M = \rho . V$(kg) (2)
= 20.664 kg

2.2.2 Determination of mass of the grating drum

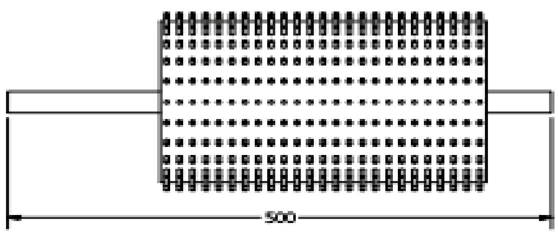

Fig. 1: Grater drum schematics

Volume of the grater = $\pi r 2 h$ (3)

Where, diameter of the grater is 300 mm, radius is 150 mm, height is 410 mm.

Velocity of the grater (V) was determined by $\pi d n$ (4)

2.2.3 Determination of power (Ps) required to drive the grater shaft
This is determined using Ps =T × ω (5)

Ps = 5.15 kW

2.2.4 Determination of grater shaft speed ratio.
This was calculated using Khurmi and Gupta (2017):

$$N_1D_1 = N_2D_2 \qquad (6)$$

Where N_1 is the angular speed driving pulley which is 1440 rpm, $D_1$is the diameter of the driving pulley which is 180 mm, N_2 is the angular speed of the driven pulley and D_2 is the diameter of the driven pulley.

2.2.5 Determination of tension acting on the driven pulley T_1 and T_2
The tension T_1 and T_2 on the driven pulley was calculated using

$T_1/T_2= \ell\mu\theta$ Khurmi and Gupta (2017) (7)

Where, T_1 is the tension at the tight side of the pulley, T_2 is the tension at the slack side of the pulley, μ is the co-efficient of friction between the leather belt and metal pulley which is 0.3 and θ is the wrap angle which is 3.065^0

2.2.6 Determination of shaft diameter
This was calculated using Khurmi and Gupta (2017);

$$d^3 = \frac{16}{\pi\,\tau}\sqrt{(K_bM_b)^2 + (K_tM_t)^2} \qquad (8)$$

Where, τ is the allowable shear stress of metal with key way which is given as 40×10^6 N/m^2,

M_b is the maximum bending moment which was 138 Nm,

M_t is the torsional moment calculated to be 69.33 Nm,

K_b and K_t were the combined shock and fatigue factor applied to bending moment and torsional moment under sudden load which were 2.0 and 2.0 respectively, according to Allen *et al*. (2014).

30 mm and 50 mm diameters was selected for grater and screw expeller respectively.

2.2.7 Design of the Screw Expeller

Fig. 2: The screw expeller

The design data used in determination of screw expeller parameters was compiled by Faculty of Mechanical Engineering, PSG College of Technology, Coimbatore 641004, India.

ISSN: 2456-3676

Capacity of the screw expeller (Q)

$$Q = \pi D^2 Sn\Psi\rho C \tag{9}$$

$$Q = 0.16\,\frac{ton}{h}.$$

Power (N) required for driving the screw expeller.

$$N = \frac{\frac{QL}{367}[W_0 \pm \sin\beta]1}{c} \tag{10}$$

$$N = 1\ kW$$

The speed of the screw expeller (V)

load propulsion speed V

$$V = \frac{Sn}{60}\ \text{or}\ Sn. \tag{11}$$

V = 0.3 m/s

Load per metric length of screw expeller, q

$$q = \frac{Q}{3.6\ v} \tag{12}$$

$$= 0.8\ N/m$$

The axial thrust (Ta) on screw expeller

$$P = ql\rho, kgf \tag{13}$$

$$Ta = 0.035\ Nm$$

Area of the outlet

$$\text{orifice}\ A = \frac{Q}{\rho v n_0} \tag{14}$$

$$Q = 0.016\ \simeq 0.02\ kg\ t0\ 20\ N$$

$\rho = 0.062\ kg/m^3$, v = 0.3 m/s

$$A = 0.062\ m\ \ \text{use}\ 0.062\ m^2$$

2.2.8 Power transmission system

The machine was powered by 2.2 kW (3.8) hP single phase, 1440 rpm Electric motor. 220 mm driving pulley with two groves of five driven pulley diameters; 235 mm 215 mm, 198 mm,185 mm and 172 mm for grater and 740 mm, 860 mm, 1020 mm,1250 mm and 1650 mm for the screw expeller were selected. The machine was designed to use an open V- belt type A for the power transmission from the electric motor to the grating and dewatering units. The belt specifications used were those that can carry the more than the maximum load.

2.3 Fabrication and Operational Principle of the Machine.

The components of the machine were assembled and mounted on the fabricated frame as designed in (Figure 1). The machine (Plate 1) was fabricated in accordance with the design specifications. Marking out of the materials for fabrication were carried out with steel rule and scribe. Other operations like cutting, filling, welding, drilling and machining were done using the appropriate and available machines in the workshop. The peeled, washed cassava tuber is fed into the machine through the hopper, under gravity the tuber slides into the fast rotating grater, the grated mash drops into the screw expeller chamber, the screw conveys and rotate the mash on a rigid sieve also there is compression force as a result of a pressure spring load on the rotating shaft of the screw that compress the mash, thereby liberate the moist starch through the sieve and the mash cake discharged through the other outlet.

Table 1: Experimental design

Variables	Level	
Cassava tuber variety	TMS 30110	**1 level**
Grater Speed	1100, 1200, 1300, 1400, 1500 rpm	**5 level**
Screw Expeller Speed	150, 200, 250, 300, 350 rpm	**5 level**
Pressure Spring force	100 N, 200 N, 300 N, 400N, 500 N	**5 level**

2.4 Test Parameters

Machine speed: The machine speed for the evaluation was set at 1100, 1200,1300,1400, 1500 rpm for grating and 150, 200, 250,300, 350 rpm for the dewatering operations using tachometer.

Machine output: Two outputs (mash cake in kg and moist starch in litres) per round of test were obtained and measured by weighing the products from the machine per time. The outputs were determined measured by the quantity discharged using Tabletop Digital Scale Standard Precision Model SC- 30 plate 3.2 and measuring cylinder were used for mash cake and moist starch respectively.

Compression spring load: The internal compressible spring force was pre-determined. Five level of the spring load 100 N, 200 N, 300 N, 400 N and 500 N were selected using spring tester.

Moisture content of the product: The ideal moisture content was based on the literature, this was set between 45 and 50% wb (IITA-ICP, 2018). The moisture content of the samples after passing through dewatering process of the machine was determined using moisture meter, meter model 4080 was used and re confirmed with conventional method for accuracy. Moist starch expressed from the sample by the machine was also measured with graduated measuring cylinder.

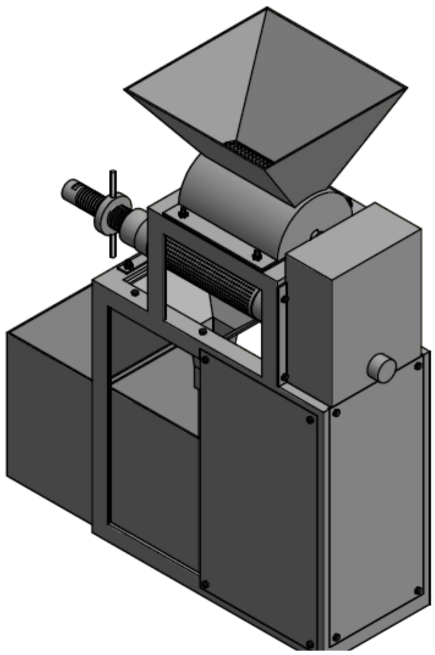

Fig. 1: Isometric view of cassava processing machine

Plate 1: Cassava processing machine

3. Results and Discussions

The effect of grater speeds (1100, 1200, 1300, 1400 and 1500 rpm on mash output and efficiency was tested on TMS 30110 cassava tuber. The variety was selected based on its proven qualities and the recommendation by IITA. The five speeds were also selected for the performance evaluation based on the recommendation of Darlene *et al*. (2019) and Doydora *et al*. (2017).

10 kg of tuber was fed into the machine at different grater speeds, the process was replicated three times to determine the average mash output per grater speed as presented in figure 4. the output and efficiency increases as speed increases up to 1400 rpm, but no increment was observed after 1400 rpm. The output obtained ranges from 7.78 kg to 8.67 kg. 1400 rpm speed has the highest mash output of 8.67 kg, while 1100 rpm has the lowest output of 7.78 kg. the

efficiency also ranged from 79.2% to 87.8%. The same observation was also observed in the grating and dewatering operations.

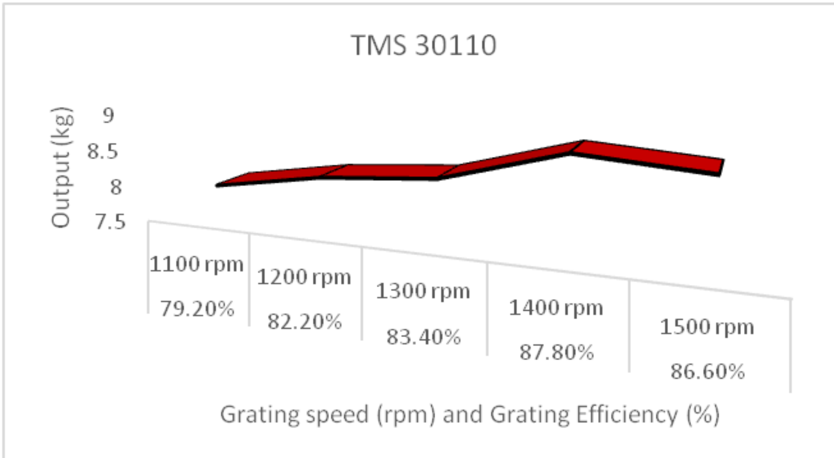

Fig. 4: Effect of Grating Speed on Mash output and Grating Efficiency.

3.2 Effect of spring load on output at various speed.

The effect of compression spring loads (100 N, 200 N, 300 N, 400 N and 500 N) was tested against the screw expeller speeds (150 rpm, 200 rpm, 250 rpm, 300 rpm and 350 rpm) at constant 1400 rpm grater speed. The spring loads and the screw expeller speeds were used in dewatering grated mash. These were selected based on the recommendation of Kolawole (2012).

The screw expeller speed and compression spring load were varied from 150 to 350 rpm and 100 to 500 N respectively in each case of the experiment and the process was replicated three times. The throughput and efficiency of the machine increased as speed increased from 150 rpm to 300 rpm also spring load from 100 N to 400 N. but no increment was observed after 300 rpm and 400 N respectively. The throughput ranges from 5.4 kg/h to 7.29 kg/h while the efficiency ranged from 66.6% to 83.7%. May while, the highest throughput and efficiency was recorded at 300 rpm expeller speed, 400 N spring load of 7.29 kg/h with 83.7% efficiency as presented in Figure 3. This agreed with the recommendation of Okonkwo *et al.* (2016) and Kolawole (2012) that the throughput of the grater and the screw expeller increased between 1300 – 1500 rpm grater speed and 250 – 300 rpm expeller speed. This indicated that the throughput increased with increased in grater and expeller speed. Ovat and Odey (2018) also revealed similar observation. The moisture content of the cassava cake ranges from 54 % to 46% wet basis, from initial moisture content 72% wb cassava mash, Therefore, speed has a significant effect on the throughput and efficiency while spring load has a significant effect on the moisture content.

4. Conclusions

The cassava processing machine that combines two units' major operations of grating and dewatering was developed. The development of the machine prototype involved design, fabrication and performance evaluation. The machine which is simple to operate and maintain was evaluated for performance in terms of grating with five speeds (1100, 1200, 1300 1400 and 1500 rpm), dewatering with five speeds (150, 200, 250, 300, and 350 rpm) and five compression spring loads (100, 200, 300, 400 and 500 N). The recommended cassava variety TMS 30110 was also used. The results obtained from the performance of the machine showed a significant improvement over similar machines. The results from performance evaluation of the cassava processing machine showed that, 1400 rpm grater speed has the highest grating capacity and efficiency.

Also in the combine machine (grating and dewatering) experiment, 1400 rpm grater speed, 300 rpm screw expeller speed and 400 N compression spring load has the highest machine capacity, throughput and efficiency of 114.23 kg/h, 95. 88 kg/h and 83.9% respectively from 10 kg cassava tuber. The moisture content 46% wb obtained was within the recommended value. Also clogged and losses recorded during machine operation was negligible

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ISSN: 2456-3676

Fig.3: Effect of Spring load on Throughput and Efficiency at various Machine Speed.

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