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Design, Fabrication and Performance Evaluation of Motor-Operated Cassava Grater

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Abstract

The motor-operated cassava grater was developed, fabricated and evaluated using locally available and low-cost materials for household-level processing. Peeled cassava tubers were grated at three various grating drum rotational speed determined by using three pulley diameters (5, 6 and 8 in) with an average speed of 1424.30 rpm, 1148.30 rpm, and 857.40 rpm, respectively. The cassava grater was run by 1.5-hp electric motor and its performance was evaluated in terms of grating capacity, grating efficiency, percentage loss and fineness modulus (FM). Each parameter was statistically analyzed using completely randomized design. The manual grating was also conducted in comparison to the fabricated machine. From the parameters tested, the 5-in diameter pulley with an average grating capacity of 283.26 kg/hr, grating efficiency of 91.56%, percentage loss of only 8.44% and FM of 3.38 is highly recommended.

Keywords*:* cassava, cassava grater, motor-operated cassava grater, manual grating

1. Introduction

Cassava (*Manihot esculenta* Crantz) is a starchy tuberous root crop belonging to the family *Euphorbiaceae* (United States Department of Agriculture, 2018). After rice, sugar, and maize, it is the fourth source of dietary energy in the tropical region and the ninth globally. It is also the staple food of roughly 800 million people worldwide. In the developing countries, cassava is considered as the drought, war, and famine crop (Burns *et al.*, 2010). It is commonly grown by low-income and smallholder farmers because of its tolerance to low soil fertility, drought, and most pest and diseases (Howeler *et al.*, 2013). Thus, dependence on this crop will expectedly rise in the coming years with the aggravation of climate change.

A major limitation of cassava is its rapid postharvest physiological deterioration. It should be processed immediately after harvest because it is highly perishable. Deterioration normally starts within 48 to 72 hours after it is taken from the ground (Smith *et al*., 1994). Hence, it is crucial that the tubers are processed as early as possible (Ajao *et al*., 2013). Moreover, processing the cassava decreases its cyanide content which is poisonous. Consequently, this prolongs the product's shelf life, reduces post-harvest losses, and prevents contamination of the products which will convert the crop safer and more merchantable (Doydora *et al*., 2017).

In rural areas, manual processing of cassava is practical. This traditional way of grating cassava is done by manually rubbing the peeled tubers against a roughened surface of galvanized mild steel on a wood or metal frame. Manual grating is tedious, time-consuming and usually results in injuries to the fingers of the operator. It can also cause development of back pain with time because of the continuous bending of the backbone. Furthermore, the manual grating of cassava leads to non-uniform quality products. The quality can differ from one operator to another, and even with the same person (Jekayinfa *et al.*, 2003). Consequently, manual grating results to non-uniform particle sizes as well as substantial losses arising from the inability of the person to hold small pieces of cassava during the rubbing process (Adetunji and Quadri, 2011).

To meet the demand of consumers, the food industry has to raise the product quality through improved processing equipment. Technology advancement and mechanization in the field of agricultural production is necessary for faster, less arduous, and more sustainable agriculture. Hence, modern agriculture requires modern approach responsive to the necessity of mankind (Doydora *et al.*, 2017). As to cassava processing, a number of equipment has been designed to replace manual grating. These include mechanized grater, motorized grater, hammer mill, disk grater, and hand grater (Odebode, 2008). A patented design of a hand-operated grater is composed of a housing with a grater barrel and crank for rotation (Grace *et al.*, 2010). Jekayinfa *et al.* (2003) also designed a pedal-operated cassava grater composing of a grating unit, transmission unit, housing, hopper, and discharge chute. Despite being mechanized, these machines are still operated by human power which limits grating capacity and efficiency.

Other designs have also been proposed like the improvised cassava grater (Adetunji and Quadri, 2011) with a grating capacity of 158 kg/hr and dual-operational mode cassava grating machine (Ndaliman, 2006), which can be powered either electrically or manually. In the Philippines, Doydora *et al.* (2017) developed a cassava grater with juice extractor. However, mechanization may not always be adoptable to the local community because of constraints in getting fuel or power (Jekayinfa *et al*., 2003), high cost of the machine and lack of operating skills (Odebode, 2008), transportation costs (Adebayo *et al.*, 2008) and corrosion of machine parts (Adetunji and Quadri, 2011). To prevent these hindrances, development of equipment and machines must be based on social and economic factors like indigenous designs and practices (Jekayinfa *et al.*, 2003), and government policy (Adebayo *et al.*, 2008).

Considering difficulties from manual grating and limitations from mechanized equipment, this research was conducted to develop, fabricate and evaluate a cassava grater that would lessen and relieve the problems encountered by local cassava farmers. This technology is also hoped to be more adoptable to farmers because of its less complex design, easier operation, and use of locally available materials. The results of this study may greatly aid Philippine policymakers because there are no local standards established for the fabrication of grating machines.

2. Methodology

In conducting the experiments, the conceptual framework in Figure 1 was followed.

2.1 Materials and Fabrication

Materials known to withstand the effects of vibration and impact forces caused by motor operation, grinding of feed materials, and other operational procedures were used in fabricating the cassava grater. Moreover, the machine (Figures 2 to 5) was composed of five major components – the hopper, housing, grating drum assembly, frame, and discharge outlet.

INPUT	PROCESS	OUTPUT
• Literature research of design data, criteria, and assumptions	• Design calculations and analysis	• Design plan and drawing
• Design plan and drawing of grater • Materials for fabrication • Equipment for fabrication	• Fabrication of cassava grater	• Fabricated cassava grater
• Cassava grater • Cassava tubers • Test equipment • Local manual grater	• Testing and evaluation of cassava grater using various diameter	• Grating time • Grating capacity • Grating efficiency • Percentage loss
• Capital investment • Data on cash flow	• Economic analysis	• Payback period

Figure 1. Conceptual framework of the study

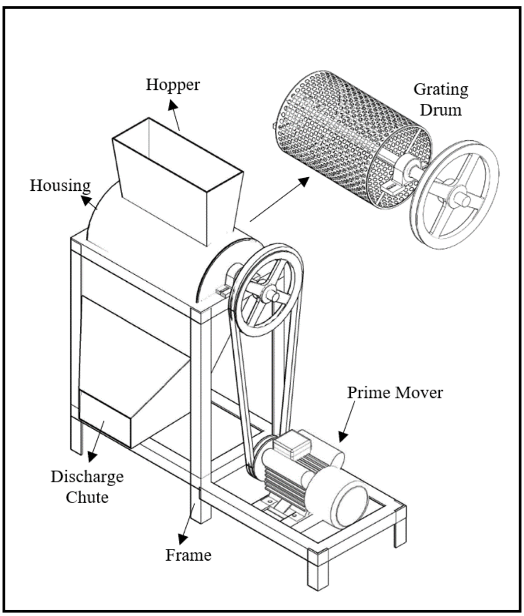

Figure 2. Perspective CAD image of the motor-operated cassava grater

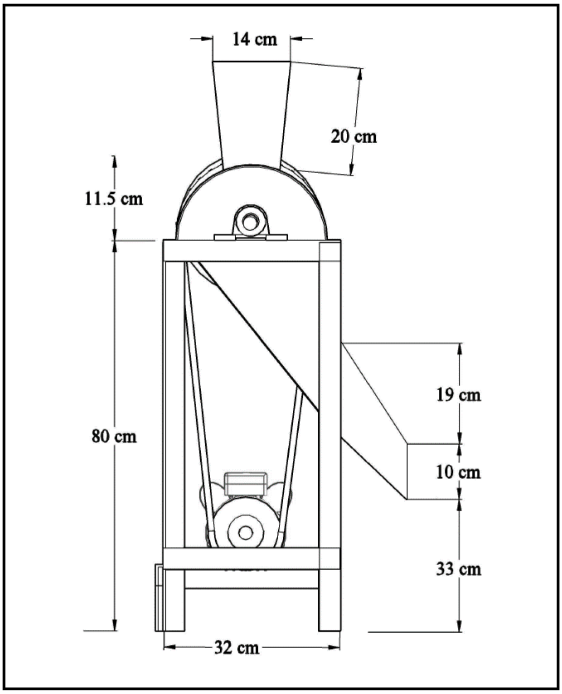

Figure 3. Front view of cassava grater

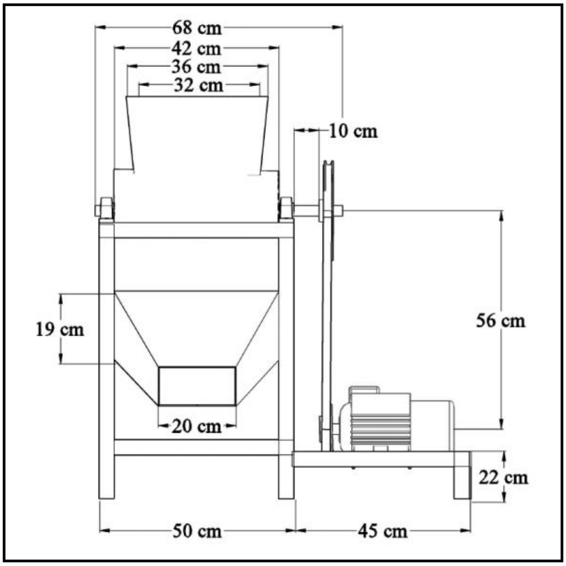

Figure 4. Right side view of cassava grater

Figure 5. Actual view of the motor-operated cassava grater

The grating assembly (Figures 6 and 7) was cylindrically designed using a black iron pipe. It was wrapped with a galvanized iron sheet that was holed with 1-in concrete nails. The diameter of the punch was approximately 2 mm with 5-mm spacing. The tooth angle for each grating surface was 45° to ensure effective contact between the cassava and the grating surface. The pillow blocks stabilized the perforated assembly that was attached to a 25-mm diameter shaft.

The grating assembly was enclosed in a cylindrical housing with a 2-in offset that would hold the cassava. Lastly, the machine had a trapezoidal hopper and a discharge outlet made from mild steel plate and with 51° inclination.

2.2 Sample Preparation

Thirty-six kilogram of fresh cassava tubers with average moisture content of 65.35% were used in the machine performance evaluation. Samples were manually peeled and sliced, and then washed thoroughly. Sample weights for each test trial were 3 kg. Three replications were conducted for each operating speed

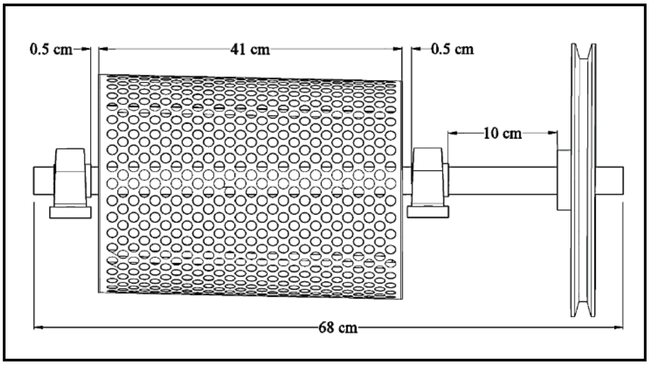

Figure 6. Front view of the grating drum assembly

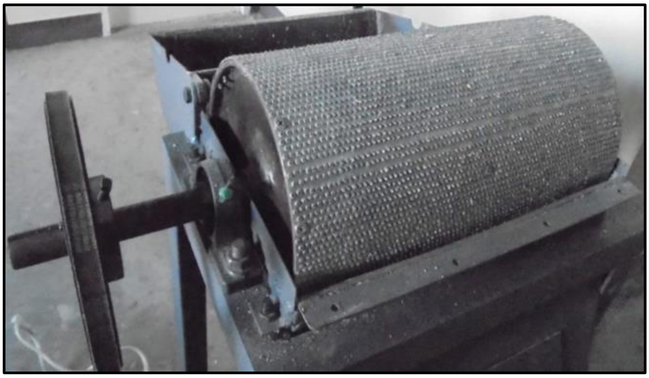

Figure 7. Actual perspective view of the grating drum assembly

2.3 Determination of Speed

Pre-testing was done in order to identify the smallest size of electric motor that causes the least detrimental vibrations. With this consideration, a 1.5-hp electric motor with an average speed of 1794.4 rpm was used for the cassava grater.

The desired range for the shaft speed (rpm) of the machine was determined by testing several rated speeds. The result of the initial evaluation was essential to the determination of the pulley size using the formula:

$$D_o N_o = D_a N_a \tag{1}$$

where:

D_o = diameter of the driver (motor), in
D_a = diameter of the driven shaft (machine), in
N_o = Speed of the driver (motor), rpm
N_a = Speed of the driven shaft (machine), rpm

2.4 Operating Procedure and Evaluation

The machine was tested and evaluated using three different pulley diameters (5, 6 and 8 in). Some parameters were also compared to the conventional manual grating.

For manual grating, a local hand grater was used. It was made from galvanized plain sheet with 2-mm diameter burred holes at 5-mm spacing and a tooth angle of 45° for each grating surface. The metal part was mounted on a wooden frame.

The operating speeds of the mechanical cassava grater were determined using a tachometer. The machine was operated empty for one minute to allow speed to stabilize. The 3-kg peeled cassava was hand fed simultaneously into the hopper. The rotating action of the perforated assembly enables the cassava to be grated. Using Philippines Agricultural Engineering Standards (PAES) (2004) methods of test for similar machines, the following formulas were used in evaluating the performance of the motor-operated cassava grater:

$$Actual\ \ Capacity = \frac{W_f}{T} \tag{2}$$

$$Efficiency = \frac{W_f}{W_i}\ x\ 100\% \tag{3}$$

$$\%\ Loss = \frac{W_i - W_f}{W_i}\ x\ 100\% \tag{4}$$

where:

W_f = total weight recovered, kg
W_i = total weight fed in, kg
T = time it took to grate the cassava tubers, s

After grating, the grated cassava from the different operating speeds were sun dried in order to measure the fineness modulus (FM). FM is one of the simplest means of describing the size characteristics of grains and powders. It indicates the uniformity of grind in the resultant product and is defined as the weight fractions retained above each sieve divided by 100. A 500-g sample of sun-dried grates was sieved for 10 min. Sieves at six different mesh number of 5, 10, 35, 60, 120 and 250 microns were used. The FM was computed using the American Society of Agricultural and Biological Engineers (ASABE) standard formula given as:

$$Fineness\ \ Modulus = \frac{Total\ \ Weight\ \ Fraction}{100} \tag{5}$$

where:

Weight fractions = (% materials retained in each sieve) (multiplier)

2.5 Data Analysis

Analysis of variance (ANOVA) in completely randomized design was used in determining and analyzing the difference between pulley diamaters based on grating time, grating capacity, grating efficiency, percentage loss, and FM.

For the economic analysis, the payback period of the motor-operated cassava grater was assessed. The wage of the operator, electricity, equipment, and raw material expenses was calculated in one-year operation with 240 working days. To compute the net annual cash flow and the payback period, the following formulas were used:

Machine Cost, Php

$$Machine\ Cost = Material\ cost + labor\ cost \tag{6}$$

Annual Cost of Raw Materials (Raw Mats.), Php

$$Raw\ Mats. = \left(\frac{quantity\ \ of\ \ \ processed\ \ materials}{day}\right)\left(\frac{price}{kg}\right)\left(\frac{days}{year}\right) \tag{7}$$

Annual Wage of the operator (Wage), Php

$$Wage\ = \left(\frac{wage}{day}\right)\left(\frac{days}{year}\right) \tag{8}$$

Annual Electricity Cost (Elec.), Php

$$Elec. = (motor\ \ power)\left(\frac{operating\ \ time}{day}\right)\left(\frac{days}{year}\right)\left(\frac{electric\ cost}{kWh}\right) \quad (9)$$

Annual Repair and Maintenance Cost (R&M), Php

$$R\&M = 30\%\ of\ machine\ cost \quad (10)$$

Income, Php

$$Income = \left(\frac{price\ of\ \ grated\ cassava}{kg}\right)\left(\frac{kg}{day}\right)\left(\frac{days}{year}\right)(efficiency) \quad (11)$$

Annual Net Cash Flow (Net Cash), Php

$$Net\ Cash = Income - (Raw\ Mats. + Wage + Elec. + R\&M) \quad (12)$$

Payback Period

$$Payback\ \ Period = \frac{Income}{Net\ Cash} \quad (13)$$

3. Results and Discussion

3.1 Grating Time

The driver pulley in operating the cassava grater was 4 inches with a speed of 1794.40 rpm. It was connected to different pulleys with sizes of 5, 6, and 8 in, with an average speed of 1424.30, 1148.30, and 857.40 rpm, respectively.

Grating time was the time that the motor-operated cassava grater took to grate the cassava from the moment it was fed into the hopper. The different pulley diameters and manual grating resulted in different grating times (Table 1). The 5-in pulley had an average grating time of 34.91 s, followed by 6-in and 8-in pulleys. The manual grating was also evaluated with an average grating time of 1601.60 s or 26.69 min. Analysis of variance where manual grating was excluded revealed significant difference among the three pulley treatments.

Table 1. Grating time, grating capacity, grating efficiency, percentage loss, and FM of the cassava grater based on pulley size

Treatments, Pulley Size (in)	Grating Time (s)	Grating Capacity (kg/hr)	Grating Efficiency (%)	Percentage Loss (%)	FM
5	34.91[a]	283.26[c]	91.56[ns]	8.45 [ns]	3.38 [e]
6	36.07[a]	270.91[c]	90.48 [ns]	9.52 [ns]	3.49 [f]
8	51.81[b]	190.93[d]	91.59 [ns]	8.41 [ns]	3.49 [f]
Manual Grating	1601.60[*]	6.26[*]	92.76 [ns]	7.24 [ns]	3.49 [f]
Mean	431.10	5.24	91.59	8.41	3.46
Coefficient of Variation (%)	9.34	9.00	1.01	3.66	0.83

*manual grating not included in the statistical analysis
**same letters denote that treatments are not significantly different at 5% level LSD

This implies that as the pulley size decreases, the grating time also decreases. This is because smaller pulleys have faster operating speed than larger ones. Moreover, the time for the manual grating is much slower compared to the machine because it depends on the person grating the cassava. The manual grating is a painful and tedious work. As stated by Opandoh (2014), manual grating would require 10 to 15 working days to grate a ton of peeled cassava.

3.2 Grating Capacity

As defined in PAES (2004), capacity is the weight of processed material collected per unit time, expressed in kilogram per hour. The 5-in pulley had the highest grating capacity with a mean of 283.26 g/hr, followed by 6- and 8-in diameter pulleys, and lastly by the manual grating with means of 270.91, 190.93, and 6.26 kg/hr, respectively. ANOVA where manual grating was excluded revealed significant differences among the three pulleys.

Hence, the speed of pulley assembly had affected the grating capacity of the machine. Since the average speed of 5-in diameter pulley is relatively fast and it could grate the cassava within a short period of time, the grating capacity of the motor-operated cassava grater is expected to be high.

3.3 Grating Efficiency

Grating efficiency is the ratio of the recovered fresh grate materials to the total fresh weight of the input of the grater (PAES, 2004). Results revealed that manual grating with the mean of 92.76% has the highest average grating efficiency followed by mechanized grating with pulley diameters of 8 in, 5 in, and 6 in. Compared to the manual grating, the motor-operated cassava grater has more losses such as unrecovered cassava which has not been discharged or those which are not grated. However, ANOVA revealed no significant differences among the four treatments. This indicates that the speed of the three different pulleys and manual grating did not affect the grating efficiency of both manual and mechanized operation.

3.4 Grating Losses

Percentage loss is the total weight input of material minus the total weight output of material over the total weight input, expressed in percentage. Manual grating had the lowest percentage loss with a mean of 7.24% followed by 8-, 5- and 6-in pulley with means of 8.41%, 8.45%, and 9.52%, respectively. There is also no significant differences among the four treatments. This means that the speed of the three various pulleys did not affect the percentage loss of the motor-operated cassava grater.

Furthermore, the most losses (Table 2) in manual grating were the ones that were not grated because the small pieces of cassava cannot be grated by hand. In the machine, the most losses were in housing with an average mean of 0.15 kg followed by expelled, hopper and grating drum. Because of the high moisture content of the raw material, some of the grated cassava remained in the housing of the grating assembly.

Table 2. Losses in grating

Pulley Size (inches)	Losses (per 3-kg sample)					Total (g)
	Hopper (g)	Grating Drum (g)	Housing (g)	Ungrated (g)	Expelled (g)	
5	17.3	2.9	157.3	0	76.0	253.5
6	20.0	5.4	145.7	0	114.6	285.7
8	42.0	14.8	133.3	0	62.2	252.3
Manual Grating	N/A	35.7	N/A	129.3	52.2	217.2

3.5 Fineness Modulus (FM)

As for the FM, ANOVA revealed highly significant differences among treatment means which means that the 5-in pulley had the finest grates among the three pulley sizes. It also implies that different speed significantly affected the FM of the cassava grates. Thus, the faster the speed of the machine, the finer the cassava grates will be. Size reduction of cassava is a vital factor to maximize the potential yield from the ground product. By increasing the surface area of particles, the availability of important food constituents like cell oils, fragrance, and flavor components are also increased (Meghwal and Goswami, 2010).

3.6 Payback Period

For the economic analysis (Table 3), only the 5-in pulley size was taken into consideration since it yielded the best results based on the parameters tested. At this setting, grating capacity is 283.26 kg/hr and grating efficiency is 91.56%.

Table 3. Annual income and expenditures

Machine Cost	27,700.00
Raw Material Cost	1,560,000.00
Wage	74,640.00
Electrical Cost	11,398.47
Repairs and maintenance	8,310.00
Income	1,757,952.00
Net Annual Cash Flow	103,603.53
Payback Period (year)	0.2673

Machine cost is the sum total of material and fabrication costs. The materials which include metal sheets, pipes, pulleys, belts, adhesives, and fittings amounted to Php 16,806.00. Meanwhile, fabrication cost of the machine was Php 10,894.00, resulting to a total machine cost of Php 27,700.00.

The cost of fresh cassava tubers is estimated at Php 6.50 per kilo. In this paper, it is assumed that the cassava grater will process one ton of cassava per day. At 240 working days a year, the cost of raw material procurement is Php 1,560,00.00

It is also assumed that there is only one operator for the machine with wage of Php 311.00 per day. This translates to a total annual wage of Php 74,640.00.

For the annual electrical cost, electricity rate of Php 11.00 per kWh was considered. At a grating capacity of 283.26 kg/hr, grating efficiency of

91.56%, and one ton of raw materials, actual machine operating time per day was computed at 3.86 hr. Assuming that only the 1.5-hp prime mover uses electricity, total annual electrical cost is estimated to be Php 11,398.47.

Repair cost includes replacement of belts, bearing, grating drum, and other parts most prone to wear and tear, while maintenance cost covers lubrication and other related operation. Machine inspection is assumed to be done only once a year. Inclusive of labor cost, total repair and maintenance is approximated to be 30% of the investment cost or around Php 8,310.00 annually.

For income computation, the cost of grated cassava is estimated at P8.00 per kilogram. For one ton processed material each day at 91.56% machine efficiency, annual income is determined to be Php 1,757,952.00.

With these considerations, the computed net annual cash flow of the motor-operated cassava grater is Php 103,603.53 and the payback period is 0.2673 year. Hence, the capital investment for the machine can be recovered in at least 3.21 months.

4. Conclusion

Different speeds of the grating assembly affected the grating capacity of the machine and the FM of grated cassava. However, speed did not affect the grating efficiency and percentage loss of the machine. Lastly, the 5-in pulley with an average speed of 1,424.3 rpm is the most suitable size as compared to 6- and 8-in pulley, as well as to the manual grating.

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