Design and manufacturing of cassava grater machine

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Abstract: This study was conducted to design and fabricate the cassava grater machine from Ethiopian-sourced materials. The worldwide demand for agricultural commodities has increased, and the use of advanced technology in agriculture is becoming increasingly important. This research work utilized stainless steel entirely for the machine's fabrication. The fabricated machine primarily comprises a feeding hopper, housing, grating drum, discharge chute, frame, shaft, and power transmission unit. The cassava grater machine was powered by a three-point seven kilowatt (3.7 kW) engine which revolves at a continuous speed. The weight determination results indicated that the weight for the machine components of the grating drum, shaft, hopper, and pulley was determined as 146.2, 58.86, 10.20, and 29.92 N, respectively. According to design analysis results, grating force, grating power, torque, belt tension, speed ratio, distance between driven and driving pulley, lap angle, and shaft diameter were found to be 293.3 N, 3.7 kW, 18.62 Nm, 1936.4 N, 1:4, 0.13 m, 2.86 rad, and 30 mm, respectively. The evaluation of the machine can be carried out at a moisture content of 54.6% on a wet basis for the 'Kello' variety according to operating speeds of 28.27 m s^{-1}, 26.18 m s^{-1}, and 21.99 m s^{-1} in line with a feeding rate of 15 kg min^{-1} with three replications. The test results showed that the operating speed of 28.27 m s^{-1} achieved the maximum grating capacity with a mean of 386.2 kg h^{-1} followed by 26.18 m s^{-1} and 21.99 m s^{-1} which achieved a grating capacity of 341.6 and 248.5 kg h^{-1}, respectively. It was also observed that the operating speeds of 28.27 m s^{-1} achieved the maximum grating efficiency with a mean of 97.1% followed by 26.18 m s^{-1} and 21.99 m s^{-1} which achieved the grating efficiency of 94.9% and 87.9%, respectively. This cassava grater machine was accessible to Ethiopian farmers.

Keywords: Cassava tuber, Design, Fabrication, Grating, Analysis

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1 Introduction

Cassava is regarded as a key food source which is the fourth most significant crop for farmers in the tropics and sub-tropics. In Africa, cassava is a crucial crop that serves as a reserve for food, raw materials for industry, and animal feed (Amelework et al., 2021). Due to its great nutritional value, seasonal availability, as well as capacity to thrive under stressful conditions, it supports alleviating food shortages in Africa (Andrade et al., 2022). In Ethiopia, cassava typically grows across almost all of the parts of the country. However, the majority of the nation's production is concentrated in the southwest, west, and south. According to a study in the southwestern region of Ethiopia, 12.7% of farmers remove the hydrogen cyanide from the cassava by grating and sun drying (Gezahegn and Bazie, 2021).

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Cassava grating is the size-reduction process that converts peeled cassava tubers into cassava mash (Umani et al., 2020). The rate of processing, the quality, and the quantity of the products, as well as their availability to users, will all be improved by mechanizing the cassava grating operation (Adiele et al., 2021). Mechanical grating of cassava can grate the cassava on a vast scope, increase the processing speed of cassava, reduce the amount of labor used, avoid direct contact, and save time so it is necessary but the manual method has grating speed limitations, labor-intensive, severe damage to the operator's fingers, and is extremely thorough (Krishnakumar et al., 2022).

Cassava has historically been the most perishable of all root crops when the roots are separated from the primary plant, resulting in post-harvest physiological decline (Hershey, 2020). Cassava roots are processed by numerous techniques into different products, the various unit operations involved include grating, peeling, slicing, fermenting, drying, and other processes. To use cassava securely as a portion of a nutritious diet for the people, suitable processing is, therefore, necessary.

Currently, there is no cassava grating machine for the processing of cassava in the south, southwestern, and western parts of Ethiopia as well as in the country as a whole. Still, now cassava producer farmers are faced with a lack of cassava grating technology in Ethiopia, and the design and fabrication of a cassava grater machine is necessary. Proper automation as well as mechanization are critical for generating the preferred final product.

Therefore, the overall objective of this research was to design and fabricate the cassava grater machine for cassava producer farmers.

2 Materials and methods

2.1 Description of the study area

The study was carried out at Melkassa Agricultural Research Center (MARC), on June 2022 up to 2023, which is located 117 km southeast of Addis Ababa, Ethiopia, and 17 km South of Adama city. It is found at an altitude of 1466 m above sea level and lies on the geographical coordinates of 8° 24' 0" N, and 39° 20' 0" E latitude, and longitude, respectively.

2.2 Materials

In this research work to automate cassava processing, a cassava grater machine was constructed from Ethiopian available materials. The strength of materials and principles were taken into consideration throughout the grater machine's fabrication. Care was given to both food quality and material toughness during the construction of the cassava processing machine (Aideloje et al., 2023).

2.2.1 Selections of materials

During the fabrication of parts of the grater that had direct interaction with the cassava root corresponding to a grating drum, high attention was given to prevent contamination of a grated mash. Therefore, a grating drum was constructed from a stainless-steel sheet metal whereas other parts like the frame, shaft, housing, hopper, and chute were fabricated from the square pipe, milled still round, and stainless-steel sheet metal to fulfill an anticipated working lifespan. The selection of materials for the constructions were based on various properties, including ease of fabrication, durability, toughness, machinability, and resistance to corrosion, wear, and tear.

2.3 Methods

2.3.1 Determining the physical characteristics

(1) Dimensions

The diameters of cassava tubers were measured using a digital venire caliper with an accuracy of 0.01 mm and a measuring range of 0.00 to 150.00 mm. This was done at the major diameter (head) taken as “a”, intermediate diameter (middle) as “b”, and minor diameter (tail) “c” based on the morphology of cassava tubers.

(2) Mass and volume

A digital weighting balance of accuracy of 0.1 g and a capacity of 15 kg weighted the mass of cassava tubers. The volume of cassava tubers could be determined by water displacement methods in such a way that the container was filled with water up to the top and placed in another container. The cassava tubers might be then immersed totally into the water filled container then the amount of water displaced was used to determine the volume of cassava tubers. Therefore, the volume of the cassava tuber determines to know the volume of the grating drum (Joshua and Simonyan, 2015).

(3) Bulk density

The bulk density of tubers was determined by weighing the cassava tubers packed in a container of known weight and volume. The container having a volume in liters and a mass in kilogram was filled with cassava tuber in a way that it might be at the top level of the containers. Then the container together with samples of cassava tuber to be weighted by a weighting balance of accuracy of 0.1 g and a capacity of 15 kg (Joshua and Simonyan, 2015).

(4) Moisture content

Moisture content for randomly selected and cleaned cassava tubers was determined. The moisture content was determined by dehydrating the samples at 105 ºC for 24 h in a drying oven, according to AOAC approved oven drying method (AOAC, 2005).

(5) Angle of repose

The angle of repose of the cassava tuber samples was determined along the length of cassava tuber samples on three test surfaces namely wood, glass and sheet metal. The cassava tuber was to be placed on the angle of the repose device which was raised slowly until the frictional force between the tuber and the test surface (wood, glass or sheet metal) was overcome by the force of gravity and movement down the slope began. The angle, at which the cassava roots start to slide, was read from a graduated protractor attached to the device which was the angle of repose of the cassava tuber (Joshua and Simonyan, 2015).

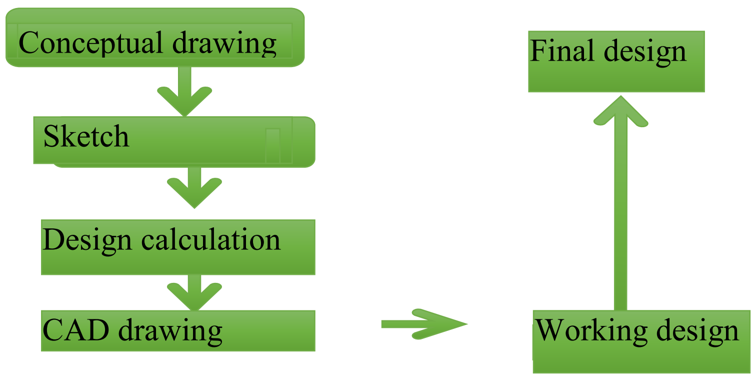


Figure 1 The design approach for the cassava grater

2.3.2 Design considerations

In the design of the cassava grater machine, a number of criteria were considered. The following were taken into account:

Cost effectiveness and functionality in both cases the materials used for fabrication of grater were affordable and effective.

Safety and operating procedures, during grating to control scattering housing were considered.

Accessibility of fabrication-related materials, this indicates availability of materials for manufacturing it for end users.

The durability of the materials used in construction, which means long-lasting materials was considered.

Food's acceptable quality, in this case, stainless steel taken due to its food-graded material.

Minimal loss of grated mash and efficient grating, in this case, tooth angle for grating surface properly considered.

Parts are simple to assemble and disassemble which means the mechanism is not complicated.

The force, torque, and power needed to grate the cassava were determined during design machine.

2.3.3 Design analysis and description of machine components

2.3.3.1 Hopper design

The fabricated cassava grater machine comprises a trapezoidal-shaped hopper composed of 1.5 mm thick stainless steel sheet metal. The grater feeding hopper was the receptacle through which cassava root was fed into the machine for grating.

The machine hopper had a length of 500 mm, a width of 400 mm, a height of 400 mm with inclination of 31.8°. It was fixed to housing and accommodated cassava root during grating. It was fixed at the upper center of the housing.

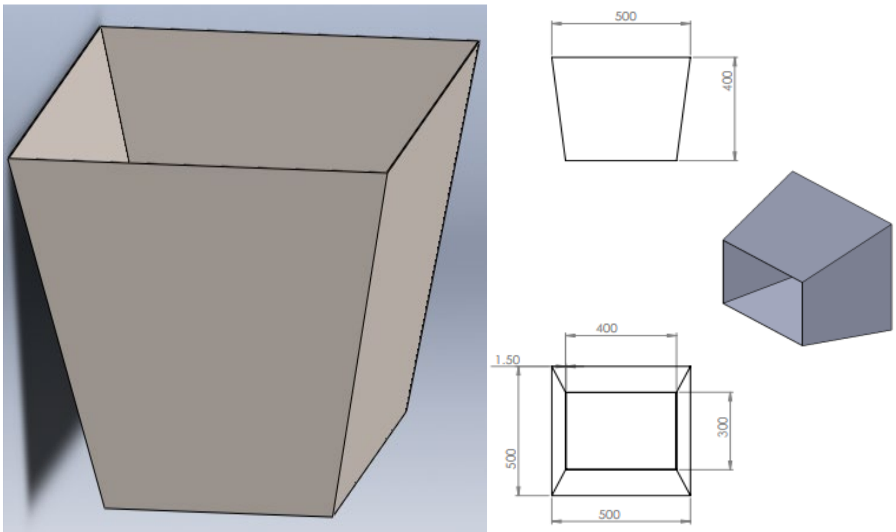


Figure 2 Detail view for designed hopper

The feeding hopper with trapezoidal cross section was considered. According to Khurmi and Gupta (2005), the volume of which was calculated as follows:

$$V = \frac{1}{3}AH \tag{1}$$

$$V = \frac{1}{3}[0.5\times(0.5+0.4)\times 0.4]\times 0.4 = \frac{1}{3}\times 0.18\times 0.4 = 0.024m^3$$

Where V is the volume of the hopper (m^3), A is the area of the base (m^2), and H is the perpendicular height (m).

2.3.3.2 Grating drum design

The grating drum was fabricated from (600 mm×400 mm×2 mm) stainless steel sheet perforated in cylindrical shape when the actual grating task takes place on it. The ongoing abrasive force delivered to the cassava root by the rough surface of the drum was accomplished by the rotating grating drum. The grating drum had a shaft that conceded through it and held by bearings at the two ends. It moves in a circular motion driven by power from a 3.7 kW engine transmitted through the V-belt. The diameter of the drum tooth was 4 mm with 8 mm tooth spacing. The tooth angle for each grating surface was 32° to guarantee effective contact between the cassava root and the grating unit.

The grating drum was cylindrical. According to Khurmi and Gupta (2005), the volume, circumference, and force acting on the cylinder drum were determined using Equations 2, 3, and 4 as follows:

$$V = \pi r^2 l \tag{2}$$

$$C = 2\pi r \tag{3}$$

$$F = V\rho g \tag{4}$$

$$V = \frac{3.14\times 0.4\times 0.4\times 0.6}{4} = 0.075m^3$$

C = 2×3.14×0.2 = 1.256 m

F = 0.024×7500×9.8 = 1,764 N

Where V is the volume of a cylinder (m^3), r is the radius of a cylinder (m), l is the length of a drum (m), g is the acceleration due to gravity (m s^{-2}), and ρ is the density of a material for stainless (kg m^{-3}).

(1) Determination of the grating force of the cassava tubers

The grating force of the cassava tubers can be calculated according to Khurmi and Gupta (2005), as follows:

$$W = M_t\times g \tag{5}$$

Where W is the weight, M_t is the total mass, which is the sum of maximum mass of tubers for each cycle of gating and the mass of grater (kg), g is the acceleration due to gravity (m s^{-2}), Therefore, the maximum mass of cassava tubers for each cycle of grating is 15 kg (measured), mass of grating drum is 14.9 kg (determined from mass properties using solid work), M_t = 15 kg+14.9 kg = 29.9 kg, and weight required by the grating machine:

W = 29.9 kg×9.81 m s^{-2} = 293.3 N, so the grating force = 293.3 N.

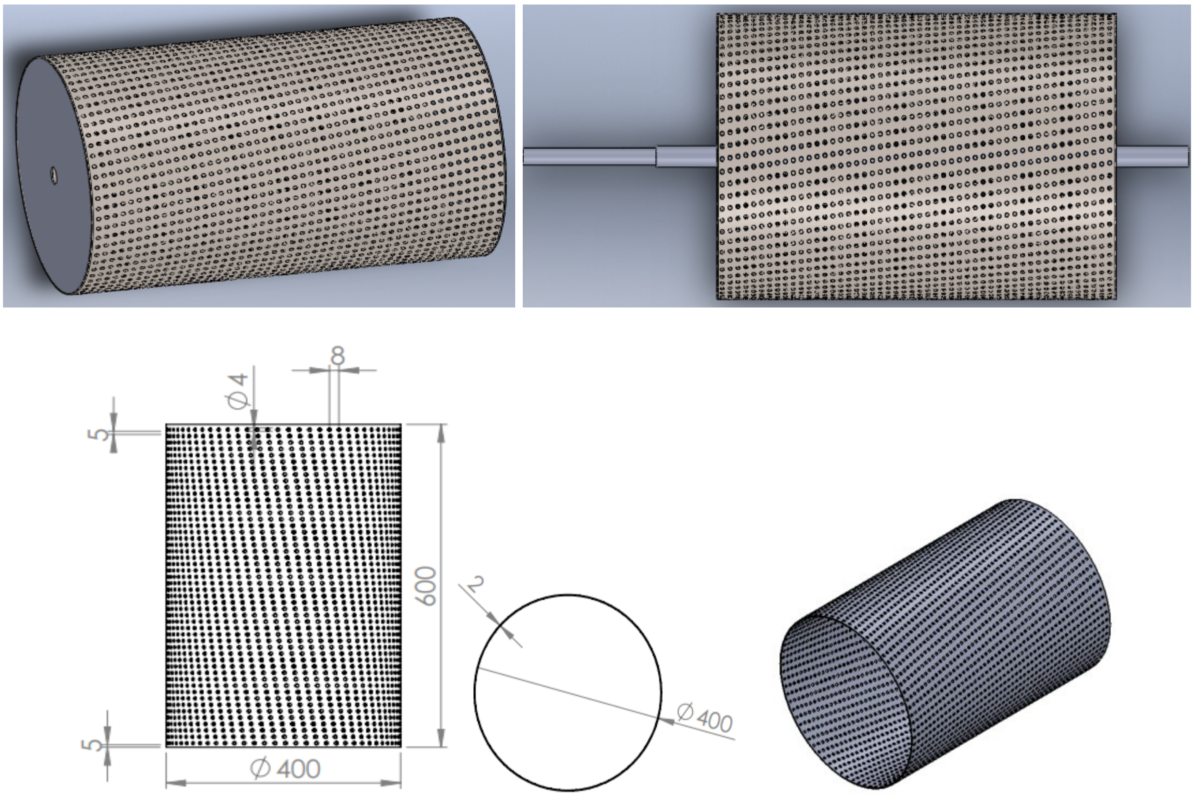


Figure 3 Designed grating drum

(2) Power required to grate the cassava tubers

The power required to grate cassava and speed can be calculated according to Khurmi and Gupta (2005).

$$P = F \times V \quad (6)$$

$$V = \frac{\pi DN}{60} \quad (7)$$

Where P is power required to turn the shaft (kW), V is speed (m s^{-1}), F is force (N), D is diameter (m), and N is speed in (rpm).Therefore,

$$P = \frac{Ma\pi DN}{60}$$

$$P = \frac{29.9 \times 9.81 \times 3.14 \times 0.1 \times 1500}{60} = 2302.55W = 3.08hp$$

Considering a safety factor of 1.5 for optimum performance, reliability, and durability (Khurmi and Gupta, 2005).

P = 3.08×1.5 = 4.6 hp≈5 hp = 3.7 kW

(3) Determination of torque

The torque was obtained from Equation 8 (Khurmi and Gupta, 2005), as follows:

$$T = F \times r \quad (8)$$

T = 293.3 N×0.0635 m = 18.62 Nm

Where T is torque (Nm), F is force (N), and r is the radius of the driven pulley (m).

(4) Design of circular plate

For the two ends closing the drum circular stainless steel sheet metal was used and its volume was found to be 2.512×10^{-4} m^3 for a single plate using Equation 9 (Khurmi and Gupta, 2005).

$$V_{cp} = \pi r^2 t \quad (9)$$

Where r is the radius of the circle (m), t is the thickness of the plate (m), and V_{cp} is the volume of the circular plate (m^3).

(5) Design of rectangular plate

The rectangular plate was fabricated in the shape of a rectangle from a 3 mm thickness stainless steel sheet metal plate so that, a rectangular structural formula as Equation 10 (Khurmi and Gupta, 2005), was used to calculate the volume of a single plate that was 1.08×10^{-4} m^3.

$$Vp = L \times w \times t \quad (10)$$

Where L is the length of the plate (m), w is the width of the plate (m), t is the thickness of the plate (m) and Vp is the volume of the plate (m^3).

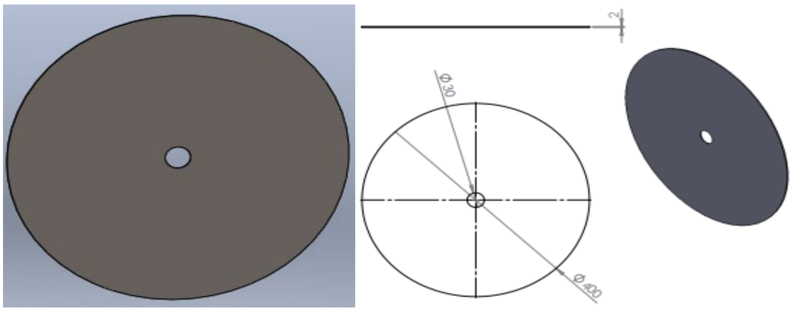


Figure 4 Drawing view of circular plate

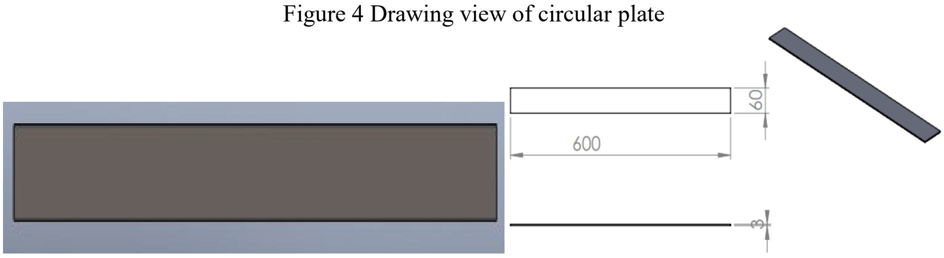


Figure 5 Drawing view of a rectangular plate

2.3.3.3 Housing design

The grating assembly was surrounded by a cylindrical housing that would grasp the cassava tuber. The drum housing was constructed from stainless steel sheet metal with a length of 640 mm, width of 520 mm, height of 350 mm, and thickness of 2 mm. It was used to protect the fragments of cassava root from the operator and also it was aided for suitable grating place.

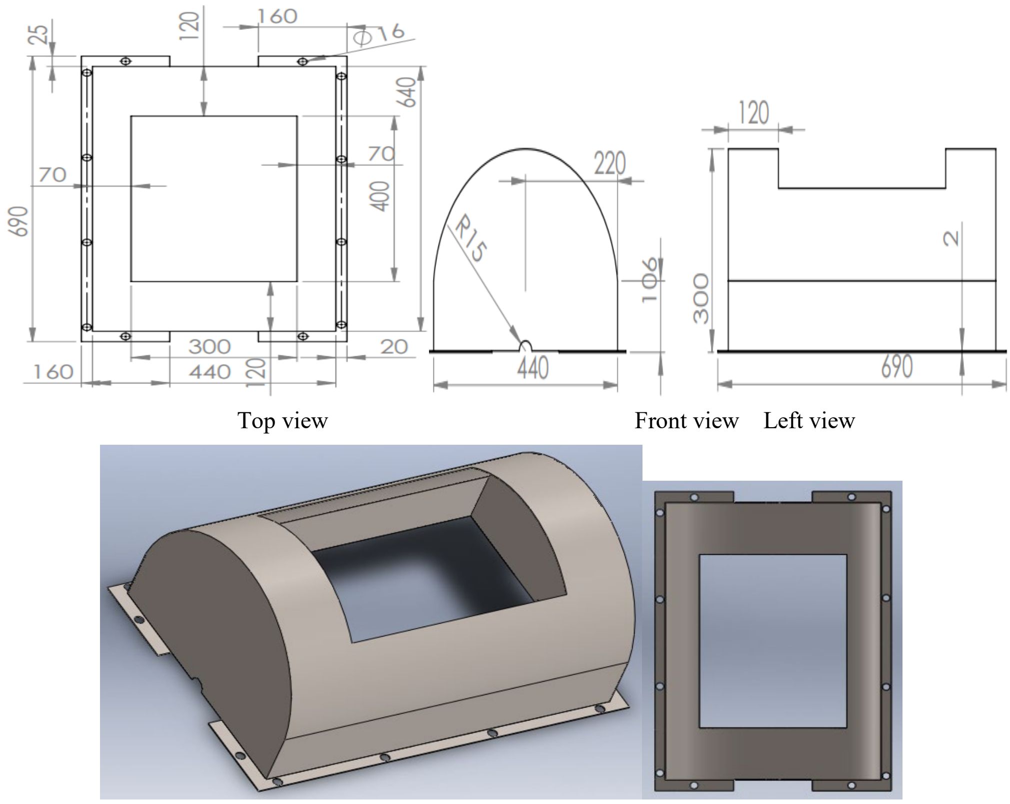


Figure 6 Isometric view for designed housing

2.3.3.4 Discharge chute design

The delivery chute was constructed from a 1.5 mm thickness of stainless steel sheet metal with a 49.3° inclination. The angle of inclination of the discharge chute was associated with the repose angle of the cassava root but it is reliant on the moisture content of the tubers. The discharge chute was an extension of the grater's frame attached to the housing and it was stable at the opened bottom of the grating unit. It directs the movement of the grated cassava to a storage pit.

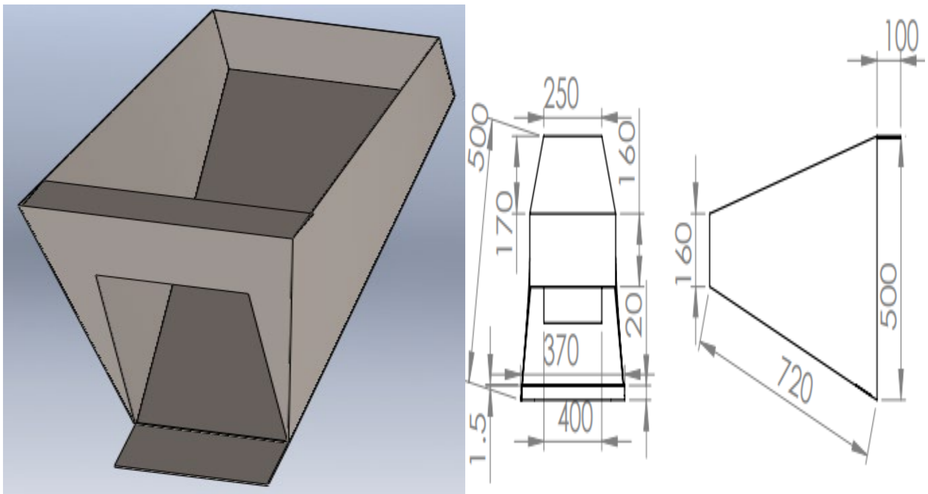


Figure 7 Designed discharge chute

2.3.3.5 Frame design

The frame of the grater machine was fabricated from hallow square pipe with a length of 640 mm, width of 440 mm, and height of 750 mm. The machine frame supports the other parts of the cassava grater machine, as well as providing stability. It was exposed to the weight of other members of the machine and also the torque and vibration from the grating drum and motor. Hallow square pipe mild steel of 4 mm thickness was selected for the machine frame. The selection of mild steel material was due to its strength and rigidity for the overall grater.

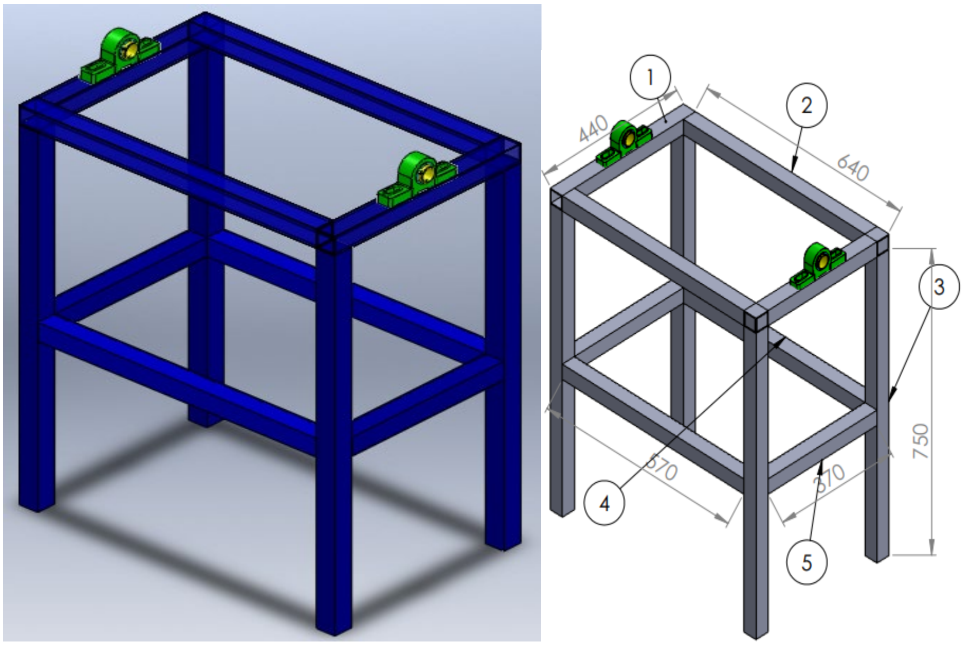


Figure 8 Frame

2.3.3.6 Shaft design

A Shaft is a collective and significant machine component. It is a revolving member, in common, has a circular cross-section and is used to deliver power.

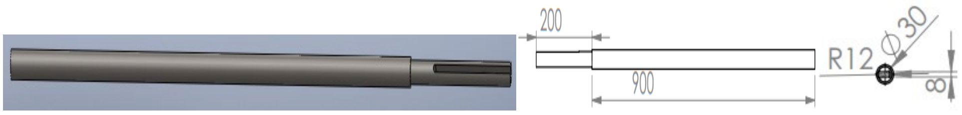


Figure 9 Designed shaft

The diameter of the shaft exposed to varied loads can be estimated using Equation 11 (Khurmi and Gupta, 2005). According to the ASMBE code for rotating shafts, when the load was applied with minor shock, the values of *Kb* = 1.2 to 2 and *Kt* = 1.0 to 1.5 It was noted that for the shaft with the keyway, the allowable stress τ should not exceed 40 MN m^{-2} (Khurmi and Gupta, 2005).

$$d^3 = \frac{16}{\pi\tau all}\sqrt{(kbMb)^2 + (ktMt)^2} \tag{11}$$

Where *d* is the diameter of the shaft (mm), τall is allowable stress (N m^{-2}), *Kb* is the combined shock and fatigue factor applied to the bending moment, *Mb* is the bending moment (Nm), *Kt* is the combined shock and fatigue factor applied to the torsional moment, and *Mt* is the torsional moment (Nm). The amount of torque applied on the motor pulley by an engine motor of 5 hp and speed of 1500 rpm was calculated to be 23.7 Nm by using Equation 12 (Khurmi and Gupta, 2005). However, according to Khurmi and Gupta (2005), the maximum torque was 25% greater than the calculated torque and can be equal to 29.6 Nm.

$$T = \frac{60P}{2\pi N} \tag{12}$$

$$T = \frac{60 \times 3728.5W}{2 \times 3.142 \times 1500\, rpm} = \frac{223710}{9426} Nm = 23.7 Nm$$

Where *P* is engine motor power (W), *N* is motor speed (rpm), and *T* is torque (Nm)

The torque and tension on the drum side were determined because the drum side torque and tension were utilized in the calculation of shaft diameter. For the drum side, toque and tension determination use the relation between speed and torque as Equation 13 (Khurmi and Gupta, 2005).

$$\frac{Tm}{Tdr} = \frac{N2}{N1} \tag{13}$$

Tdr = 1.36×29.6 Nm = 40.4 Nm, *Tdr* = (*T1-T2*) *r*2 , 40.4 Nm = (*T1-T2*) *N*×0.068 m

$$T1\text{-}T2 = 594.1 \text{ N} \tag{a'}$$

Where *Tm* is the torque on the motor pulley (Nm), *Tdr* is the torque on the drum pulley (Nm), *N1* is motor speed (rpm), *N2* is drum speed (rpm), and *r2* is the radius of the driven pulley (m).

According to Khurmi and Gupta (2005), the wrap angle, angle of the lap, and belt tension for an open belt can be obtained using Equations (14), (15), and (17), respectively.

$$\sin\alpha = \frac{r2 - r1}{c} \tag{14}$$

$$\theta = 180 - 2\sin^{-1}\left(\frac{D2 - D1}{2c}\right) \tag{15}$$

$$C = \frac{(D1 + D2)^2}{2} + D1 \tag{16}$$

$$2.3\log\left(\frac{T1}{T2}\right) = \mu\theta \tag{17}$$

Where *r1* is the radius of drive pulley (mm), *r2* is the radius of driven pulley (mm), α is wrap angle (°), θ1 is the angle of a lap for driving pulley (rad), θ2 is the angle of a lap for driven pulley, *C* is center to center distance between pulleys (m), *D1* is the diameter of the drive pulley (m), *D2* is the diameter of driven pulley (m), μ is coefficient of friction, *T* is tension in the tight side of the belt (N), and *T2* is tension in the slack side of the belt (N).

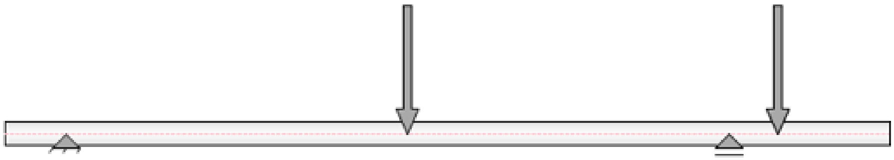
From Equations (14), (15), and (16) warp angle, lap angel, and center distance for drum side belt and pulley can be calculated as 7.95°, 2.86 rad, and 0.13 m, respectively.

$\log\left(\frac{T1}{T2}\right) = \frac{0.4 \times 2.86}{2.3} = 0.5$, take anti log, $\frac{T1}{T2} = e^{0.5} = 1.65$

$$T1 = 1.65T2 \tag{b'}$$

From Equation a' and b' T_1 = 1508 N, T_2 = 914 N

Therefore, the load on the shaft due to the belt was the sum of tension on both the tight side of the belt and the slack side of the belt which means 1,508 + 914 = 2,419 N was weight applied by the belt and pulley on the shaft. The other weight applied on the shaft was the weight of the drum and the maximum weight of cassava root loaded to the grater. From weight determination, the total mass of the drum was 14.9 kg and the machine is designed to be loaded a maximum of 15 kg. Therefore, the weight due to drum and cassava root was 29.9×9.81 = 293.3 N. The shear force, bending moment and reaction force correspond to bearing support can be determined by analysis of the shaft using Autodesk inventor 2016.



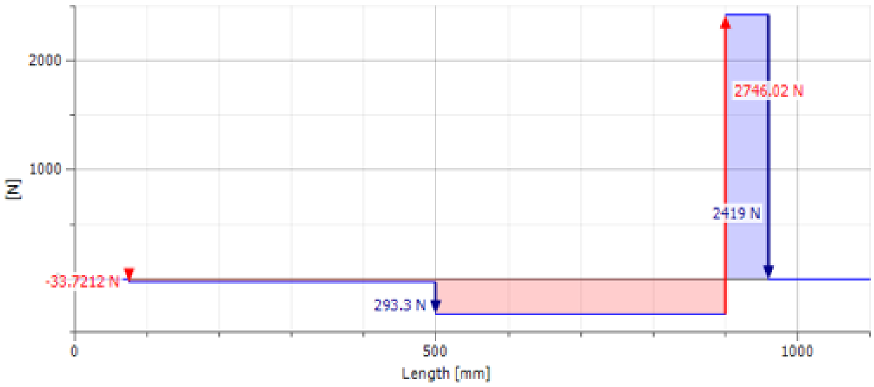


Figure 10 Shear force diagram

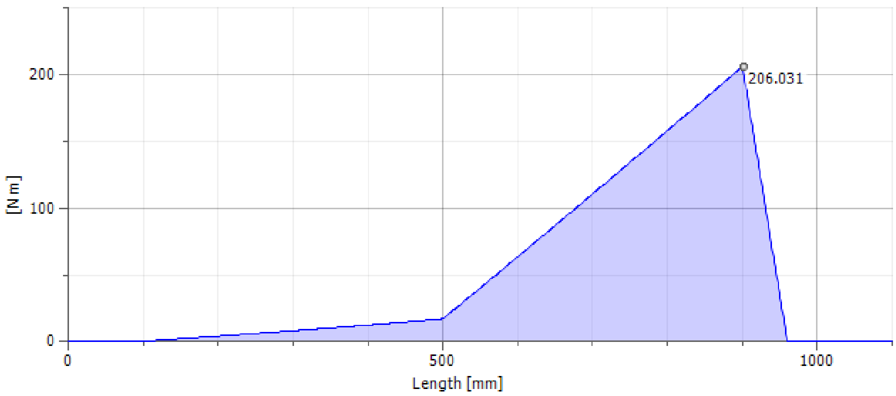


Figure 11 Bending moment diagram

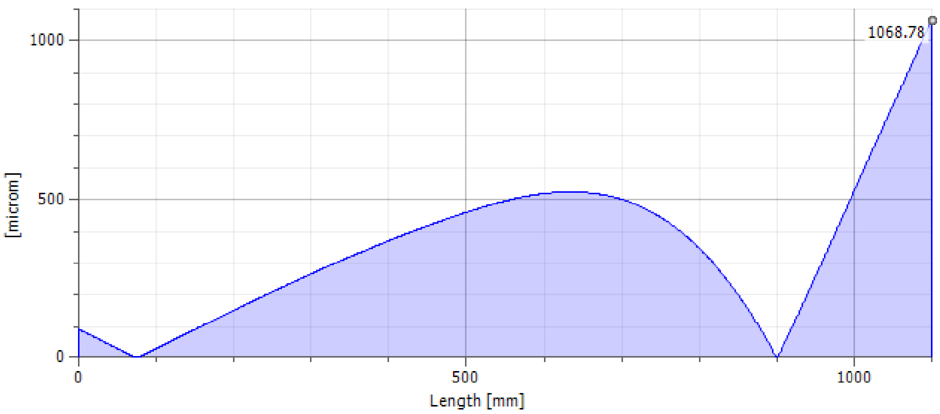


Figure 12 Deflection

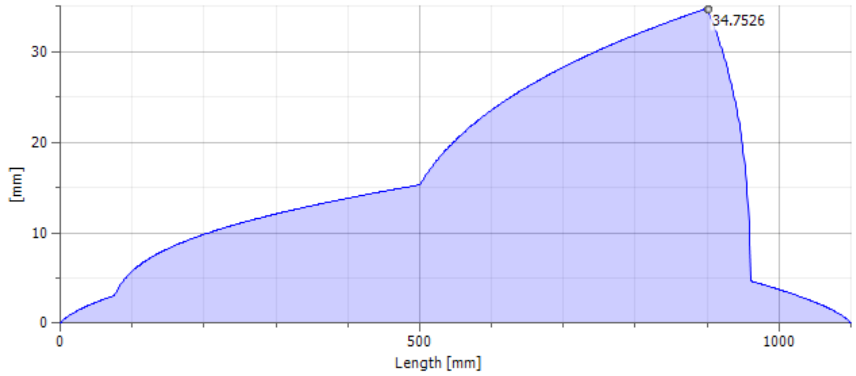


Figure 13 Ideal diameter

From the bending moment diagram, the maximum bending moment was Mb = 206031×10^3 N mm, from Equation 12 the torque exerted on the shaft Mt = 23.7×10^3 N mm and from Equation 11 diameter of the shaft can be calculated as

$$d^3 = \frac{16}{3.14 \times 40}\sqrt{(1.2 \times 206031Nmm)^2 + (1.5 \times 23700Nmm)^2}$$

$$d = \sqrt[3]{32471.39mm} = 31.9mm \approx 30mm$$

2.3.3.7 Pulley design

From power transmission components, pulleys were one of the most common means of power transmission, indeed they need careful design.

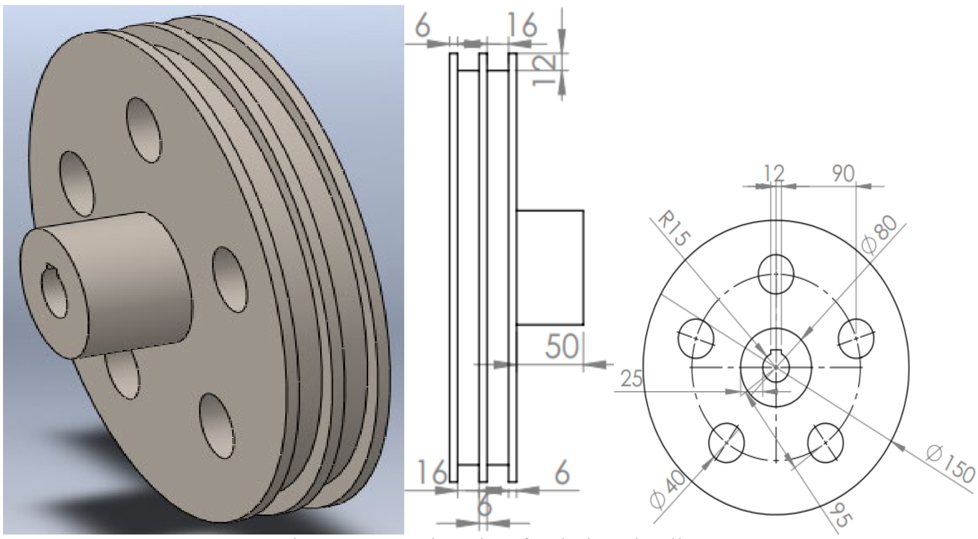


Figure 14 Drawing view for designed pulley

The velocity ratio for belt drive is the ratio between the driver's and the follower's velocity (driven). It could be stated mathematically as:

$$\frac{N2}{N1} = \frac{D1}{D2} \tag{18}$$

$$D_2 = \frac{1500rpm \times 100mm}{1100rpm} = 136mm$$

Where D_1 is the diameter of the driver (mm), D_2 is the diameter of the driven (mm), N_1 is the speed of the driver (rpm), and N_2 is the speed of the driven (rpm). If the appropriate speed of the motor was 1500 rpm, it was selected to overcome the load. The optimum drum speed was chosen as 1100 rpm due to the grating of material in the designed cassava grater. The pulley size decreases, and the grating time also decreases according to studies by Esteves et al. (2019).

2.3.3.8 Belt selection

Based on Equation 19 A-section belt having the belt code 50, inner length 1270, and outer length 1300 for both motor side and drum side was chosen for the development of the grater. According to Khurmi and Gupta (2005), the nominal pitch length "L" can be calculated using Equation 19 therefore, the belt length can be found as follows:

$$L = 2C + 1.57(D2 + D1) + \frac{(D2 - D1)^2}{4C} \quad (19)$$

2.3.3.9 Power transmitted by the belt

Power delivered by the V-belt and the speed of the belt can be obtained using Equations 20 and 21 (Kuwabara et al., 1998).

$$P = (T1\text{-}T2)\ V \quad (20)$$

$$V = \frac{\pi DN}{60} \quad (21)$$

Therefore; from belt tension, $T1$ = 1,205.7 N, $T2$ = 730.7 N,

P = 3,728.75 watt

$$V = \frac{3.14 \times 0.1 \times 1500}{60} = 7.85\ ms^{-1}$$

Where P is belt power (watts), V is belt speed (m s^{-1}), N is the speed of pulley (rpm), and D is the diameter of pulley (m)

Number of belts required = Motor power/power per belt (22)

$$Number\ of\ belts\ required = \frac{3728.5}{3728.75} \approx 1$$

L = 1.14 m = 1140 mm, taken as standard 1,270 mm.

2.3.4 Determination of weight of machine component

2.3.4.1 Mass of shaft

The shaft was constructed from a carbon steel bar with a diameter of 30 mm and length of 1.1 m to calculate the mass it was essential to know about the area and volume of the shaft. The area, volume, mass, and weight of the metallic shaft were calculated using Equations 23, 24, 25, and 26 (Khurmi and Gupta, 2005).

$$A_{sh} = \pi \times r^2 sh \quad (23)$$

$$V_{sh} = A_{sh} \times L_{sh} \quad (24)$$

$$M_{sh} = V_{sh} \times \rho \quad (25)$$

$$W_{sh} = M_{sh} \times g \quad (26)$$

From the above Equations (23), (24), (25), and (26) the values founded as A_{sh} = 7.06510^{-4} m^2, V_{sh} = 77.715 × 10^{-5} m^3, M_{sh} = 5.98 kg ≈6kg, and W_s = 58.86 N.

Where A_{sh} is the area of the shaft (mm^2), r_{sh} is the radius of a shaft (mm), V_{sh} is the volume of the shaft (m^3), L_{sh} is the length of the shaft (m), M_{sh} is the mass of the shaft (kg), ρ is the density of carbon steel kg m^{-3}), and W_{sh} is the weight of shaft (N).

2.3.4.2 Mass of grating drum and hopper

The mass of the drum and feeding hopper was found to be 14.9 kg and 1.04 kg from mass property using solid work and the weight of the drum and hopper were calculated to be 146.2 N and 10.20 N by using Equations 27 and 28 (Khurmi and Gupta, 2005).

$$W_d = M_d \times g \quad (27)$$

$$W_h = M_h \times g \quad (28)$$

2.3.4.3 Mass of pulley

The mass of the pulley was determined 3.05 kg from mass property using solid work. The weight of the pulley was obtained as 29.92 N using Equation 29 (Khurmi and Gupta, 2005).

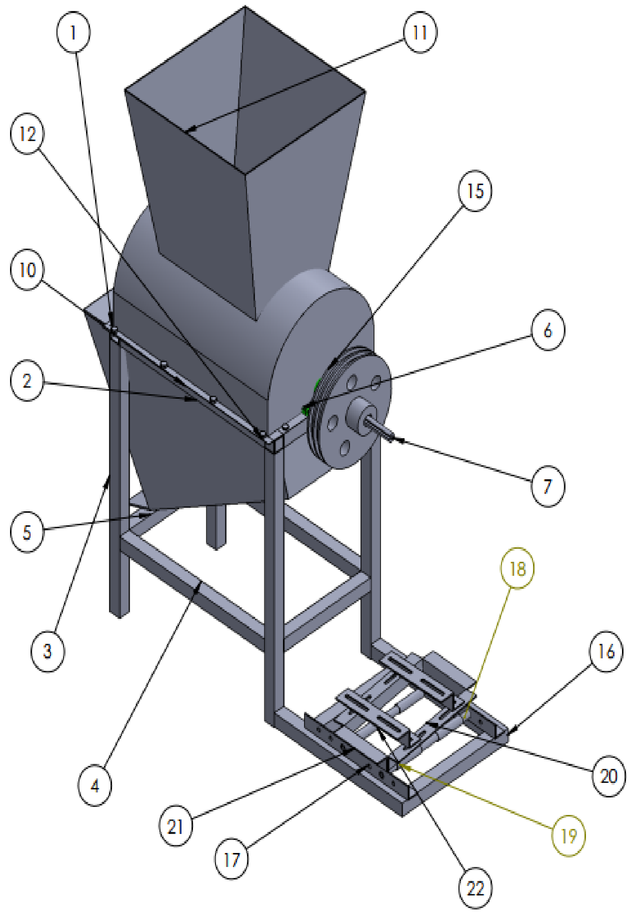
$$W_p = Mp \times g \quad (29)$$

Where W_d is the weight of the drum (N), M_d is the mass of the drum (kg), g is the acceleration due to gravity (m s^{-2}), W_h is the weight of the hopper (N), M_h is the mass of the hopper (kg), W_p is the weight of aluminum pulley (N), and M_p is mass of aluminum pulley (kg).

2.4 Description of the machine

The fabricated cassava grater machine shown below in Figure 15 was composed of the following components hopper, housing, grating drum, discharge chute, frame, shaft, pulley, bearing, V-belt, engine setting, bolt, and nut. The overall length of the machine was 640 mm, a width of 440 mm, and a height of 1380 mm. The grater machine was coupled to an engine motor by a V-belt pulley on the shaft. The continuous abrasive force applied to the cassava root by the rough surface of the drum was achieved by the rotating grating drum.

The fabricated machine had the following key features: The tooth angle for each grating surface was done at 32°, to ensure efficient interaction between the cassava root and the grating unit. The machine was fabricated from stainless steel, the reason for selecting stainless steel for the fabrication of the grater was that it had direct contact with the food to be processed and prevent contamination. The size of the machine component was larger than the other existing graters which means the drum diameter was 400 mm and the drum length was 600 mm for the fabricated machine. The feeding hopper shape was designed to guarantee safe feeding and grating.



1. Frame width
2. Frame length
3. Frame height
4. Length support
5. Width support
6. Housing
7. Shaft
10. Discharge chute
11. Hopper
12. Bolt and nut
13. Rectangular plate
14. Bearing
15. Pulley
16. Rectangular pipe
17. Base angle iron
18. Hallow pipe larger
19. Hallow pipe smaller
20. Lower angle iron
21. Side angle iron
22. Upper angle iron

Figure 15 3D drawing for grater

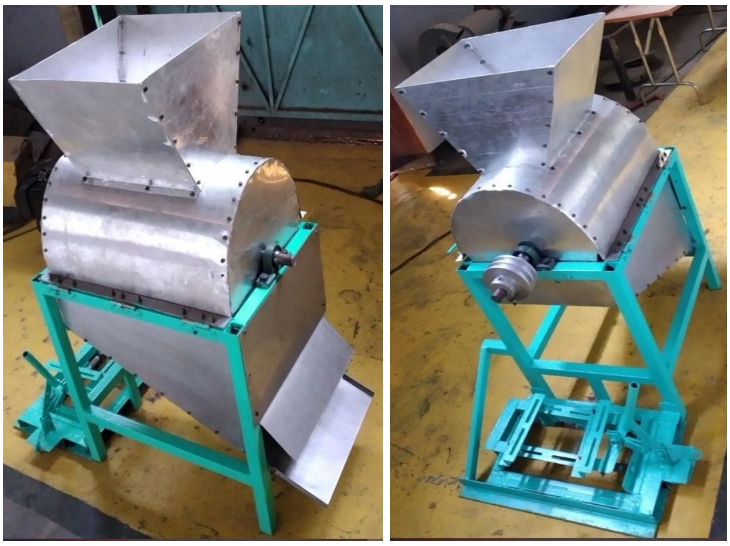


Figure 16 Prototype of fabricated grater

2.5 Working principles of the machine

The grater machine consists of the grating unit in which the grating operation occurs. The rotation of the grating unit was transferred through the V-belt, pulleys, shafts, and bearings by the torque of the engine motor. The cassava root was manually fed continuously into the grater through the feeding hopper into the grating drum. These roots came in contact with the grating unit, they were macerated into cassava pulp this occurs when the grating unit revolves, the perforated grating drum tooth continuously grates the cassava root into mash while the grated cassava moves down into the discharge chute and gathered by a bowl.

2.6 Evaluation parameters

The evaluation of the grater was carried out considering the grating capacity, efficiency, mechanical loss, and grating time. The capacity, efficiency, and percentage of mechanical damages were calculated using Equations 30, 31 and 32 (Yusuf et al., 2019)

$$Grating\ capacity\ \left(kg\ h^{-1}\right)\ = \frac{Wwg}{Tg} \tag{30}$$

$$Grating\ capacity\ \left(kg\ h^{-1}\right)\ = \frac{Wwg}{Wi} \times 100 \tag{31}$$

$$Mechanical\ loss = \frac{Wi - Wtg}{Wi} \times 100 \tag{32}$$

Where W_{wg} is the mass of well-grated cassava (kg), W_{tg} is the mass of total grated cassava (kg), W_i is the initial mass of cassava tuber (kg), and T_g is the grating time (h).

2.7 Statistical data analysis

The collected data were analyzed using Statistix 8 software, a commercial software package developed by the United States Department of Agriculture (USDA). Comparison between treatment means was conducted by least significant difference (LSD) at a 5% level. The experiment was carried out by a completely randomized design (CRD) of the three levels of operating speed with feed rate taken as treatment.

3 Results and discussion

While designing the cassava grater machine, the physical properties of the cassava such as angle of repose, moisture content, volume, bulk density and dimensions were taken into account to attain both a successful and productive primary processing machine. The angle of repose was a highly significant parameter in designing the cassava grater machine which was needed for the design of the hopper was determined as 31.8° and for the discharge chute or outlet, it was determined as 49.3°. This might serve as the foundation for the design of the discharge chute and feeding hopper.

In this research work, proper design considerations were taken into account to attain the best possible functionality for this grater machine. The mass determination results indicated that the mass for the machine components of the grating drum, shaft, hopper, and pulley were determined as 146.2, 58.86, 10.20, and 29.92 N, respectively. Based on the results, the volume of the cylindrical drum and feeding hopper was estimated as 0.0754 and 0.024 m^3, respectively which was appropriate for holding cassava tuber during grating. With the continuous nature of the grating operation, that volume was sufficient to grate masses of cassava tubers every day.

According to design analysis results, grating force, grating power, torque, belt tension, speed ratio, distance between driven and driving pulley, lap angle, and shaft diameter were estimated as 293.3 N, 3.7 kW, 18.62 Nm, 1936.4 N, 1:4, 0.13 m, 2.86 rad, and 30 mm, respectively. So, this design analysis helped for effective and efficient grating of cassava tuber at optimum capacity and efficiency with minimum loss. In this design analysis, the design criteria were effectively analyzed during the design of the cassava grater machine.

3.1 Evaluation of machine for Kello variety cassava tuber

The evaluation for the fabricated machine can be carried out at a moisture content of 54.6% on a wet basis and 31.7% on a dry basis at three different operating speeds and one feed rate according to operating speeds of 28.27 m s^{-1} (1350 rpm), 26.18 m s^{-1} (1250 rpm) and 21.99 m s^{-1} (1050 rpm) in line with a feeding rate of 15 kg min^{-1} with three replications. During the test, it was observed that the operating speed of the machine was high which caused vibration, loss of mash, and return out the feed but the operating speed was low, which also caused too low capacity, stopping operation and ungrated cassava. The test of the machine was carried out using freshly harvested Kello variety cassava tuber from farmers of the Wolayta zone for the entire test run.

3.1.1 Grating capacity

According to Esteves et al. (2019), capacity was measured in kilograms per hour as the weight of processed material collected in a certain amount of time. The grating capacity of the engine-driven cassava grater is shown in Table 2. Among these operating speeds, results showed that the operating speed of 28.27 m s^{-1} had the maximum grating capacity with a mean, maximum, minimum, and standard deviation of 386.2, 389.5, 383.8, and 2.9 kg h^{-1} followed by 26.18 m s^{-1} and 21.99 m s^{-1} with the means of 341.6 and 248.5 kg h^{-1}, respectively for the fabricated machine. The grating capacity obtained in this study was greater compared to the amount of 114.94 kg h^{-1} reported by Temam (2020) tested at Kello variety cassava tuber.

Table 1 The test run for fabricated machine

No.	Operating speed (m s^{-1})	Feed rate (kg min^{-1})	Capacity (kg h^{-1})	Efficiency (%)	Percentage of loss (%)	Grating time (s)
1	21.99	15	247.3	87.9	10.06	186
2	21.99	15	247.1	86.8	11.1	184
3	21.99	15	251.3	87.2	10.8	182
4	26.18	15	344.3	94.5	5.5	147
5	26.18	15	338.9	95.4	4.6	151
6	26.18	15	341.5	94.9	5.06	149
7	28.27	15	383.8	97.5	2.9	140
8	28.27	15	389.5	96.8	3.7	136
9	28.27	15	385.3	97.06	3.05	138

Table 2 Capacity of grater at different operating speeds and feeding rate levels

No.	Operating speed (m s^{-1})	Feed rate (kg min^{-1})	Capacity (kg h^{-1})				
			Mean	SD	Max	Min	Cv
1	21.99	15	248.5[a]	2.4	251.3	247.1	0.95
2	26.18	15	341.6[b]	2.7	344.3	338.9	0.79
3	28.27	15	386.2[c]	2.9	389.5	383.8	0.77

The results shown in Figure 17, the grating capacity of the machine tended to increase with the increase of operating speed which means grating capacity had a direct relationship to the operating speed of the machine.

3.1.2 Grating efficiency

As stated by Esteves et al. (2019), grating efficiency is the ratio of recovered fresh grate materials to the total fresh mass of the grater's input. The grating efficiency of the engine-driven cassava grater was shown in Table 3. From these operating speeds, results indicated that the operating speeds of 28.27 m s^{-1} had the maximum grating efficiency with a mean of 97.1% thereafter 26.18 m s^{-1} and 21.99 m s^{-1} with the means of 94.9% and 87.9%, respectively. Esteves et al. (2019) stated a mean grating efficiency of 91.6% at 1424.30 rpm while testing a motor-operated grater.

As shown in Figure 18, the grating efficiency of the grater had a tendency to increase with the increase in operating speed which means grating efficiency had a direct relationship to the operating speed.

3.1.3 Percentage of loss

As stated by Esteves et al. (2019), the percentage of mechanical loss was the total weight input of material minus the total weight output of material over the total weight input, expressed in percentage. The percentage loss of the engine-driven cassava grater is shown in Table 4. Of these operating speeds, findings showed that the operating speeds of 28.27 m s^{-1} had the minimum percentage of loss with a mean of 3.27% then 26.18 m s^{-1} and 21.99 m s^{-1} with means of 5.05% and 10.65%. During the test, it was observed that some losses occurred in the grating drum because of the high moisture content of the cassava tuber. Malomo et al. (2014) reported a loss of 10.3% while evaluating a cassava grater.

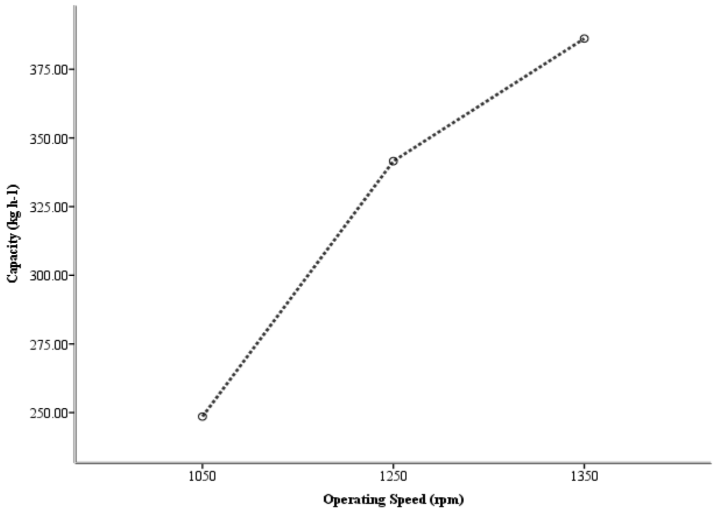


Figure 17 Effect of operating speed on grating capacity

Table 3 Efficiency of grater at different operating speed and feeding rate levels

No.	Operating speed (m s^{-1})	Feed rate (kg min^{-1})	Efficiency (%)				
			Mean	SD	Max	Min	Cv
1	21.99	15	87.3^{a}	0.56	87.9	86.8	0.63
2	26.18	15	94.9^{b}	0.45	95.4	94.5	0.48
3	28.27	15	97.1^{c}	0.35	97.5	96.8	0.36

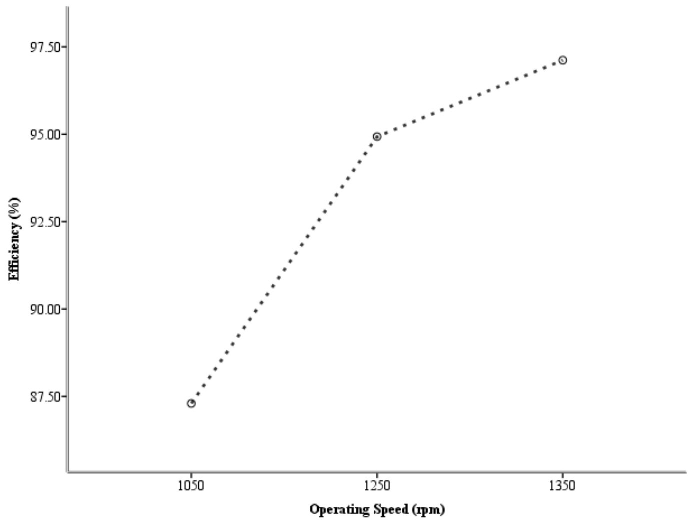


Figure 18 Effect of operating speed on grating efficiency

Table 4 Percentage loss of grater at different operating speeds and feeding rate levels

No.	Operating speed (m s^{-1})	Feed rate (kg min^{-1})	Percentage of loss (%)				
			Mean	SD	Max	Min	Cv
1	21.99	15	10.65^{a}	0.54	11.1	10.06	5.0
2	26.18	15	5.05^{b}	0.45	5.5	4.6	8.9
3	28.27	15	3.27^{c}	0.43	3.7	2.9	13.2

Figure 19 shows that the percentage loss of the machine decreased with the increase of operating speed which means percentage loss had an inverse relationship to the operating speed.

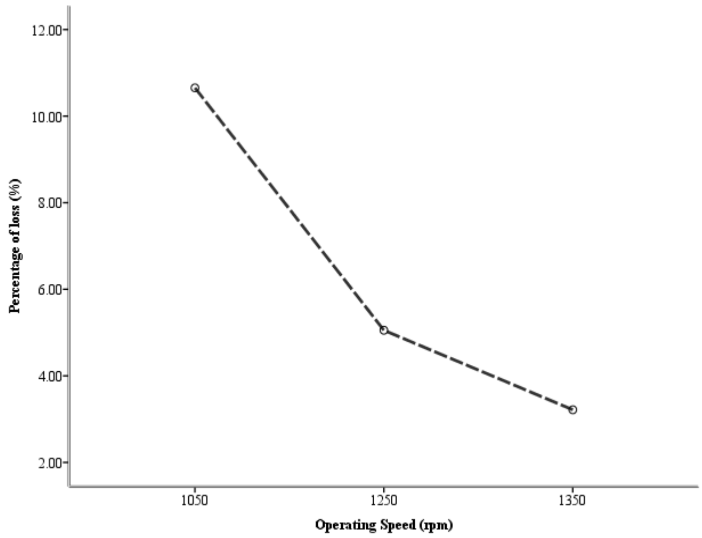


Figure 19 Effect of operating speed on percentage of loss

3.1.4 Grating time

Table 5 Grating time of grater at different operating speeds and feeding rate levels

No.	Operating Speed ($m\ s^{-1}$)	Feed rate ($kg\ min^{-1}$)	Grating time (sec)				
			Mean	SD	Max	Min	CV
1	21.99	15	184.0 a	2.0	186.0	182.0	1.08
2	26.18	15	149.0 b	2.0	151.0	147.0	1.34
3	28.27	15	138.0 c	2.0	140.0	136.0	1.45

As stated by Esteves et al. (2019), grating time was the time that the engine-operated cassava grater took to grate the cassava from the moment it was fed into the hopper. The grating time of the engine-driven cassava grater is shown in Table 5. From these operating speeds, results revealed that the operating speed of 28.27 $m\ s^{-1}$ had the minimum grating time with a mean of 138 s followed by 26.18 $m\ s^{-1}$ and 21.99 $m\ s^{-1}$ with the means of 149 s and 184 s, respectively.

The LSD all pairwise comparisons test of grating capacity, efficiency, loss and time for operating speeds was given above in Tables 4, 5, 6, and 7 then this analysis was subjected to LSD all pairwise comparisons test of dependent variables for three different operating speed and feeding rate of 15 kg min^{-1} to know significant differences among treatment means. Therefore, LSD all pairwise comparisons test showed that there were 3 groups (a, b, c) in which the treatment or operating speeds means were significantly different from one another at 5% level based on LSD all pairwise comparisons test.

Table 6 Comparison of grater machine with manual method

No.	Method of grating	Capacity ($kg\ h^{-1}$)	Efficiency (%)	Percentage of loss (%)
1	Grater machine	358.55	93.06	6.85
2	Manual method	18.7	53.3	46.7

3.2 Comparison of grater machine with manual method

When comparing the output, it was obvious that the engine-driven grater was quicker and highly stress-free to operate and quite effective. From the below table 6, results revealed that the efficiency of the cassava grater machine was greater (93.06%) as compared with the manual method which had an efficiency of 53.3%. It can also be observed from Table 6 that the grater machine was accomplished more rapidly with higher capacity and lower losses compared with the manual one thus lowering time intake and tedium which generally was associated with the manual method.

4 Conclusion

The cassava grater machine was designed, fabricated, and tested to minimize laborious work over the manual method of cassava grating. Stainless steel was entirely used for the fabrication of a cassava grater machine whereas square pipe and angle iron were used for the fabrication of the frame and engine setting. The physical properties of cassava essential for designing cassava grater were determined. To guarantee an efficient cassava grater machine with well grating functionality, the power needed to grate the cassava, the force needed to grate the cassava, the torque needed to turn the shaft, the bending moment, shear force, as well as shaft diameter were all computed. The weight determination results showed that the weight for the machine components of the grating drum, shaft, hopper, and pulley was determined as 146.2, 58.86, 10.20, and 29.92 N, respectively.

The test for the grater machine was carried out concerning capacity, efficiency, percentage of loss, and grating time. The test results revealed that these dependent variables were observed in the range of 248.5 kg h^{-1} to 386.2 kg h^{-1}, 87.3% to 97.1%, 3.27% to 10.65%, and 138 s to 184 s, respectively. The findings showed that the efficiency of the cassava grater machine was found to be higher (93.06%) in comparison to the manual method, which had an efficiency of 53.3%. It is recommended that the machine be incorporated with peeling parts and include a movable wheel for easy transportation from place to place.

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