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Performance Evaluation of Diesel Engine Operated Cassava Grating Machine

Amanuel Erchafo ERTEBO[a*]

[a]Department of Mechanical Engineering, School of Mechanical, Chemical and Materials Engineering, Adama Science and Technology University, Adama, ETHIOPIA

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Corresponding Author: Amanuel Erchafo ERTEBO, E-mail: *amanbaaman40@gmail.com*
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ABSTRACT

This research work was carried out to assess the performance of a diesel engine-operated cassava grating machine. The factorial design was used to conduct the experiment and the collected data were analysed using Statistix 8 software. The results of the analysis of variance revealed that the speed, feeding rate, as well as their interaction effect, were significant at the 5% level. The highest throughput capacity of 471.4 kg h^{-1} was observed at a speed of 1400 r min^{-1}, at a feeding rate of 5 kg min^{-1}, while the lowest throughput capacity was 272.5 kg h^{-1} observed at a speed of 1100 r min^{-1}, at a feeding rate of 5 kg min^{-1}. The highest grating efficiency of 97.3% was observed at a speed of 1400 r min^{-1}, at a feeding rate of 15 kg min^{-1}, while the lowest grating efficiency was 81.6% observed at a speed of 1100 r min^{-1}, at a feeding rate of 5 kg min^{-1}. The lowest percentage of mechanical loss of 2.45% was observed at a speed of 1400 r min^{-1}, at a feeding rate of 15 kg min^{-1}, while the highest percentage of mechanical loss was 18.4% observed at a speed of 1100 r min^{-1}, at a feeding rate of 5 kg min^{-1}. The fuel consumption of the machine was measured as 1.82 L h^{-1}. Finally, the regression analysis results for throughput capacity showed that 95% of throughput capacity was recorded with both independent variables together, $F(2, 33) = 311.17$, $R = 0.974$, $p = 0.000$. This machine was recommended for cassava grating at an operating drum speed of 1400 r min^{-1}.

Keywords: *Throughput capacity, Efficiency, Percentage of loss, Grating time, Physical properties*

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a year-round plant with a delicious root, that is produced globally in different climatic regions. Cassava is one of the most popular foods in Africa and served as the foundation of food sources for Africans due to its significance and adaptability. Approximately one billion people worldwide consume cassava (Musa *et al.*, 2022). The majority of the cassava farmed in Africa is utilized for food consumption, with 50% being processed and 38% being used fresh or boiled; the remaining 12% being used as animal feed (Amelework *et al.*, 2021). Cassava is the biggest supplier of carbohydrates as food in the world, with Africa being its primary production region (Musa *et al.*, 2022).

Cassava has a significant role in feeding a sizeable section of the Ethiopians in day-to-day life. It is also an important staple food well known in the south and southwest regions (Sarka *et al.*, 2017). In the southern area of Ethiopia, cassava was grown on 195,055 ha, a production of 501,278.5 tons annually in total in 2013 (Feyisa, 2021). Cassavas makes major contributions to assuring year-round access to sustainable food, revenue generation, resource conservation, and food security.

The critical drawback of cassava tuber is fast physiological degradation. The crop should need processing quickly because of its extreme perishability. Degradation usually begins from forty-eight to seventy-two hours when it is removed from the field (Musa *et al.*, 2022). Cassava has historically been the most perishable of all root tubers when the tubers are cut off from the main plant, they become unpleasant two to three days after harvest, resulting in post-harvest physiological decline (Okoli and Okonkwo, 2019). The cyanide (cyanogenic glucosides) that the cassava plant generates is dangerous and when taken can cause nausea, vomiting, headaches, dizziness, and exhaustion hence, it is critical that the tubers are processed as initially as possible (Fadeyibi and Ajao, 2020). The presence of hydrogen cyanide in cassava is the primary worry of the consumer during use therefore unit operation of the cassava tuber reduces hydrogen cyanide concentration it is toxic (Doydora *et al.*, 2017). Also, upon harvest, cassava is massive and holds a high amount of moisture, estimated as 70%, and both the roots and leaves contain changeable amounts of cyanide, which is toxic to human health (Nyamekye, 2021).

Grating cassava with manual method results in time-consuming, less effective, low quality and quantity of product, and exposes mold development on the skins (Krishnakumar *et al.*, 2022). To hand grate, one tonne of freshly peeled cassava roots generally requires 10 to 15 man days of effort (Moreno *et al.*, 2021). However, a mechanical grater of cassava can grate the cassava on a large scale; improve the speed of cassava processing, save labor input, avoid direct contact, and save time. Mechanized grating of fresh cassava into mash contributes to reducing postharvest losses of cassava, increasing its shelf life, and improving food security. The main benefit of an engine-operated cassava grater was reducing human power requirements and easy grating operation.

Currently, the use of advanced technology in agriculture is crucial since the demand for agricultural products increased globally. Therefore, this study aimed to evaluate engine-operated cassava grater in terms of performance indicators, fill the technology gap in cassava processing in cassava growing areas of Ethiopia, avail the technology for future intervention, and generate information about machine performance for end users. The other purpose of this work was to reduce women's drudgery and grating the tuber in high quality and quantity in a short time by replacing manual grating with the machine.

MATERIALS and METHODS

Study area

The investigation for performance evaluation of the cassava grating machine was conducted in southern areas, it is situated 341 km from Addis Ababa, the capital city of Ethiopia. This region is located between 4°27' and 8°31' north latitude and 34°11' east longitude, altitude of the region varies from 376 to 4207 m above sea level.

Materials

Experimental materials

A sample of cassava (Figure 1) was obtained from southern areas, farmer's fields of the Wolayta, offa, and Sodo districts to calculate the physical characteristics and to conduct initial and detailed tests on cassava grater.

Figure 1*. Cassava tuber samples.*

Measurement device and tools

Various devices and techniques were utilized to perform various measurements on the cassava. The length of the cassava tuber was measured using a tape meter this measuring tape can measure a minimum length up to 0.5 cm, therefore, its sensitivity is 0.5 cm. The tuber diameters were measured with a Vernier caliper with its 0.01 mm accuracy; the sensitivity of the Vernier Caliper is 0.02 mm which means that the smallest measurement that can be read using this instrument is 0.02 mm. The weighing balance could be used to take the mass of the root both earlier and subsequently when it was grated. The sensitivity of a digital weighing balance is 1 mg; this means that a weight of at least 1.0 mg is needed to move the pointer over one scale and the smallest weight that the scale can measure. A smartphone stopwatch app was used to take time during the evaluation of the grater. The machine's drum speed was measured using a non-contact type of tachometer. The sensitivity of the tachometer is 0.043 v rad^{-1} sec this means that the minimum measurement that can be read using this tachometer is 0.043 v rad^{-1} sec, a measuring distance of 50 mm to 500 mm and a measuring range of 2 r min^{-1} to 99,999 r min^{-1}. Additionally, a knife was used by hand to partially reduce the size of the cassava tuber. Therefore, a stopwatch, digital weighing balance, digital Vernier caliper, knife, tachometer, and pocket meter were used in the experiment.

Methods

Determination of physical characteristics

The first producer in automated cassava processing, Adetan *et al.* (2005) state that a thorough understanding of its physical characteristics is essential. A thorough understanding of the physical characteristics of agricultural products is important for operating post-harvest machinery. For the determination of each physical property such as geometric mean diameter, length, sphericity, bulk density, moisture content, and angle of repose, an experimental sample was randomly selected as 32, 26, 32, 28, 22, and 24 respectively. Therefore, the following physical properties have been studied:

Geometric mean diameter

A digital Vernier caliper with a 0.01 mm precision and a 0.00 to 150.00 mm measurement range was used to measure the diameters of cassava tubers. Based on the shape of cassava tubers, this was done at the major diameter (head), where "a" was taken, the intermediate diameter (middle), "b," and the minor diameter (tail), "c." An average amount for the geometric mean diameter of cassava root can be determined using Equation 1 (Joshua and Simonyan, 2015).

$$GMD = \sqrt[3]{a \times b \times c} \tag{1}$$

Where GMD is geometric mean diameter (mm), *a* is major diameter (mm), *b* is intermediate diameter (mm), and *c* is minor diameter (mm).

Sphericity

The sphericity of cassava tuber samples was determined using the formula by (Edeh *et al.*, 2022) given in Equation 2.

$$\text{Sphericity} = \frac{\text{GMD}}{a} \tag{2}$$

Where *GMD* is the geometric mean diameter (mm) and *a* is the major diameter (mm).

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 kilo gram 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)

Moisture content for cassava tuber

According to an oven drying procedure approved by the AOAC (Memmert Ule500, Germany), the samples were dried for 24 hours at 105ºC to measure the moisture content (AOAC, 2005). For the determination of the moisture content of cassava tuber, the following method was used as given in Equation 3 (Ndirika and Oyeleke, 2006).

$$M_c\,(wb)\,\% = \frac{Ww - Wd}{Ww} \times 100 \tag{3}$$

Where W_w is weight for wet tuber in gram, W_d is weight for dried tuber in gram and M_c is moisture content of tuber.

Angle of repose

The cassava tuber was set on the angle of repose device and gradually raised until the force of gravity overcame the frictional force between the tuber and the test surface, which was made of sheet metal, glass, and wood, allowing the tuber to start to down the slope. A graduated protractor attached to the apparatus measured the angle at which the cassava roots begin to slip or 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.

Experimental procedure

The initial test of the grater can be carried out at four different speeds as well as three different feeding rates based on drum speeds of 1100 r min^{-1} (46.08 m s^{-1}), 1200 r min^{-1} (50.3 m s^{-1}), 1300 r min^{-1} (54.5 m s^{-1}), and 1400 r min^{-1} (58.6 m s^{-1}) corresponding to feed rates 5 kg min^{-1}, 10 kg min$^{-1,}$ and 15 kg min^{-1} before conducting the detailed test of the cassava grater. The drum speeds were selected for evaluating the grater performance on cassava tuber according to studies by Esteves *et al.* (2019). For performance evaluation of the grater, three hundred sixty kilograms (360 kg) of freshly harvested cassava root Hawassa variety without any degradation could be utilized for experimenting. The machine was started, and the speed was adjusted to 1100 r min^{-1} (46.08 m s^{-1}), 1200 r min^{-1} (50.3 m s^{-1}), 1300 r min^{-1} (54.5 m s^{-1}), and 1400 r min^{-1} (58.6 m s^{-1}) by using a tachometer. A weighing scale was used to measure the freshly harvested cassava tuber in batches of 5 kg, 10 kg, and 15 kg for each drum speed after the tuber was manually peeled with knives and cleaned with water for hygienic purposes.

Evaluation of the grating machine

Evaluation of the grater (Figure 2) was carried out considering the grating capacity, efficiency, percentage of mechanical loss, grating time, and quality of mash. The following formulas were used to evaluate engine-operated cassava grater using the Philippines Agricultural Engineering Standardization (PAES) (2004) techniques of testing for related machineries.

$$\text{Throughput capacity (kg h}^{-1}) = \frac{Wf}{T} \tag{4}$$

$$\text{Grating efficiency (\%)} = \frac{\text{Wf}}{\text{Wi}} \times 100 \quad (5)$$

$$\text{Percentage of loss} = \frac{\text{Wi} - \text{Wf}}{\text{Wi}} \times 100 \quad (6)$$

$$\text{Quality performance efficiency} = \frac{\text{G}}{\text{G+B}} \times 100 \quad (7)$$

Where Wf is final weight collected in kilogram, Wi is initial weight in kilogram, T is time duration required grating root in hour, G is good quality or fine grated mash (kg), and B is bad quality or coarse grated mash (kg).
is bad quality or coarse grated mash (kg).

Figure 2. *Machine during operation.*

Economic analysis
The analysis of fixed and running costs for the cassava grating machine was done by the selling price of the machine, interest, depreciation, labor, and fuel costs. While running cost for the working model of cassava grater were calculated in Ethiopia Birr using the standard procedure, the calculations were based on the Philippines Agricultural Engineering Standards (PAES) (2004).

$$Dp = \frac{\text{SP} - \text{SV}}{\text{EL}} \quad (8)$$

$$IC = \frac{\text{SP+SV}}{\text{2U}} \times I\% \quad (9)$$

$$LW = \frac{\text{DLW}}{\text{DWH}} \quad (10)$$

Where Dp is depreciation (EB h^{-1}), SP is selling price of grater, SV is salvage values, EL is economic life, IC is interest on capital (EB h^{-1}), U is annual use, I is interest, LW is labor wages (EB h^{-1}), DLW is daily labor wage, and DWH is daily working hours.

Statistical analysis

The experimentation was conducted using factorial design while the machine speeds were considered as the blocking variable as well as the four levels of speeds with three levels of feeding rate taken as treatment combination or treatment (4×3 = 12). Each experiment to be replicated thrice there were 36 experimentation units (4×3×3 = 36). The collected data were analyzed using Statistix 8 software. The confidence intervals of 95% were utilized to indicate a significant effect of an independent variable on the dependent variable. A two-way analysis of variance was implemented on the data by following an appropriate procedure for the design of the experiment (Gomez & Gomez, 1984).

RESULTS AND DISCUSSION

Physical properties for cassava tuber

Table 1 shows that the mean physical characteristics of the cassava tuber samples for the Hawassa variety were calculated. So, results indicated that the mean value for geometric mean diameter was 14.05 mm while the highest as well as lowest amounts were 15.5 and 13.19 mm, respectively. The minimum value for the bulk density was 2.08 g cm^{-3} while the maximum value was 2.25 g cm^{-3} with a mean of 2.18 g cm^{-3} based on a result obtained for cassava tuber. According to the findings, the mean moisture content of 52.9% in a wet basis for the fresh sample was determined and the maximum value was 53.8% and the minimum value was 52%. The maximum angle of repose of 30° was obtained whereas the minimum angle of repose of 28.7° was obtained with its mean of 29.4°.

Table 1. *Physical characteristics for cassava tuber.*

Properties	Mean	SD	Mean±SD	Max	Min	CV
Length (mm)	316.7	135.0	316.7±135.0	450.0	180.0	42.6
Geometric mean diameter (mm)	14.05	1.279	14.05±1.27	15.5	13.19	9.1
Sphericity	0.89	0.024	0.89±0.024	0.91	0.87	2.6
Bulk density (g cm^{-3})	2.18	0.090	2.18±0.090	2.25	2.08	4.2
Moisture content (%)	52.9	0.9	52.9±0.9	53.8	52	1.7
Angle of repose (°)	29.4	0.665	29.4±0.665	30.0	28.7	2.3

CV = Coefficient of variation, SD = Standard deviation

The test result showed that grating worked better when the tuber's moisture content was higher. It was also found that the higher moisture level of the root increased the grating quality of the grater. The grated mash was found to be cohesive during the test; at increasing moisture content, it spreads flatter. This indicated that to move the mash granules inside the machine, the mash needed more inclination. The findings showed that a cohesive mash was indicated by a higher angle of repose, whereas a lower angle indicated a free-flowing mash.

The performance of the grater was evaluated at four levels of drum speeds and three levels of feed rates with respect to throughput capacity, efficiency, mechanical loss, grating time, as well as quality performance efficiency. Once the machine had finished grating, measurements were taken of the final output mash, grating time, good quality, and bad quality mash were measured. Based on the test results, it was found that every batch of cassava root that was put into the machine was grated. During performance evaluation, the specific energy consumption of the machine was calculated as 0.004 L kg^{-1}.

Throughput capacity

Table 2 shows an analysis of variance (ANOVA) for effect of speed, feeding rate, as well as interaction effect on the capacity of the grating machine. Therefore, analysis of variance revealed that effect of speed, feeding rate, as well as interaction effect was significant at a 5% level based on a result obtained (Table 2) because the p values were lower than 0.05 ($P< 0.05$). The findings implied that the throughput capacity of a machine was affected by operating drum speed, feed rate, and interaction effect.

***Table 2**. Analysis of variance for throughput capacity of the grating machine.*

Source	DF	Sum of squares	Mean squares	F-value	P-value	Remark
Block	2	18	9.1			
Drum speed	3	129708	43235.9	589.27	0.0000	Significant
Feed rate	2	3519	1759.4	23.98	0.0000	Significant
Speed×Feed	6	3267	544.4	7.42	0.0002	Significant
Error	22	1614	73.4			
Total	35	138125				

CV = 2.39, grand mean = 358.55, $P < 0.05$, significant at 5 % level, DF = degrees of freedom.

As shown in Figure 3 the average throughput capacity of the machine ranged from 272.5 kg h^{-1} to 471.4 kg h^{-1}. As the increasing speed from 1100 r min^{-1} to 1400 r min^{-1}, throughput capacity increased from 272.5 to 471.4 kg h^{-1}. When the capacity of the grater tended to increase with the increase in speed but it decreased through a feeding rate (Figure 3). This result means throughput capacity had a direct relationship to the drum speed and was inversely related to material feed rate.

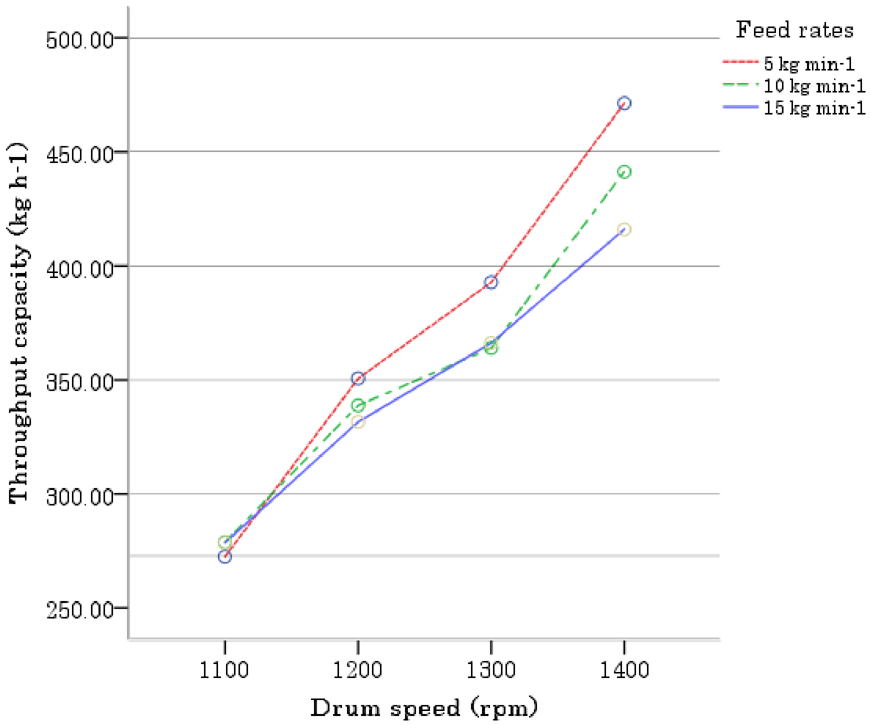

Figure 3. *Effect of speed and feed rate on capacity.*

The highest throughput capacity of 471.4 kg h^{-1} was observed at a speed of 1400 r min^{-1} as well as feeding rate of 5 kg min^{-1}, while the lowest throughput capacity was 272.5 kg h^{-1} observed at a speed of 1100 r min^{-1} and feeding rate of 5 kg min^{-1}.

The throughput capacity obtained in this study was higher compared to the value of 114.94 kg h^{-1} reported by Temam (2020). In comparison, Esteves *et al.* (2019) reported an average grating capacity of 283.26 kg h^{-1} at 1424.30 r min^{-1} when testing the performance of a motor-operated cassava grater. Ogunjirin *et al.* (2020) stated the grating capacity of 250 kg h^{-1} at 78.4 r min^{-1} when grating cassava with a cassava grater. Malomo *et al.* (2014) reported a machine output of 80 kg h^{-1} while assessing the performance of an automated grater. Bello *et al.* (2020) stated an output of 158.9 kg h^{-1} when testing an electric motor-powered machine.

Grating efficiency

Table 3 shows an analysis of variance for speed, feeding rate, as well as their interaction effect on the efficiency of the machine. While analysis of variance revealed that the main effect of speed, feeding rate, as well as their interaction effect was significant at a 5% level because the p value obtained in (Table 3) was less than 0.05 ($P< 0.05$). Therefore, the results implied that effect of speed, feeding rate, as well as their interaction effect did affect the grating efficiency of a grating machine.

Table 3*. Analysis variance for grating efficiency of grating machine.*

Source	DF	Sum of squares	Mean squares	F-value	P-value	Remark
Block	2	0.285	0.143			
Drum speed	3	339.010	113.003	137.87	0.0000	Significant
Feed rate	2	138.868	69.434	84.72	0.0000	Significant
Speed×Feed	6	113.186	18.864	23.02	0.0000	Significant
Error	22	18.032	0.820			
Total	35	609.382				

CV = 0.97, grand mean = 93.063, $P < 0.05$, significant at 5 % level, DF = degrees of freedom.

As shown in Figure 4 it was found that an average grating efficiency for grater ranged from 81.6% to 97.3%. With increasing drum speed from 1100 r min^{-1} to 1400 r min^{-1}, grating efficiency increased from 81.6% to 97.3%. The grating efficiency of the machine tended to increase with an increase in speed as well as feed rate. This means grating efficiency had a direct relationship to the speed as well as feeding rate of cassava tuber.

From the test results, the efficiency of the machine was increased with an increase in drum speed but is sudden drop or decrease of efficiency at drum speed of 1300 r min^{-1} and at a feed rate of 5 kg min^{-1} was observed. So, the decrease in efficiency occurred because of the low output recorded during the testing machine at a feeding rate of 5 kg min^{-1}. This low output was obtained when the drum was rotated, it returned the feeds back.

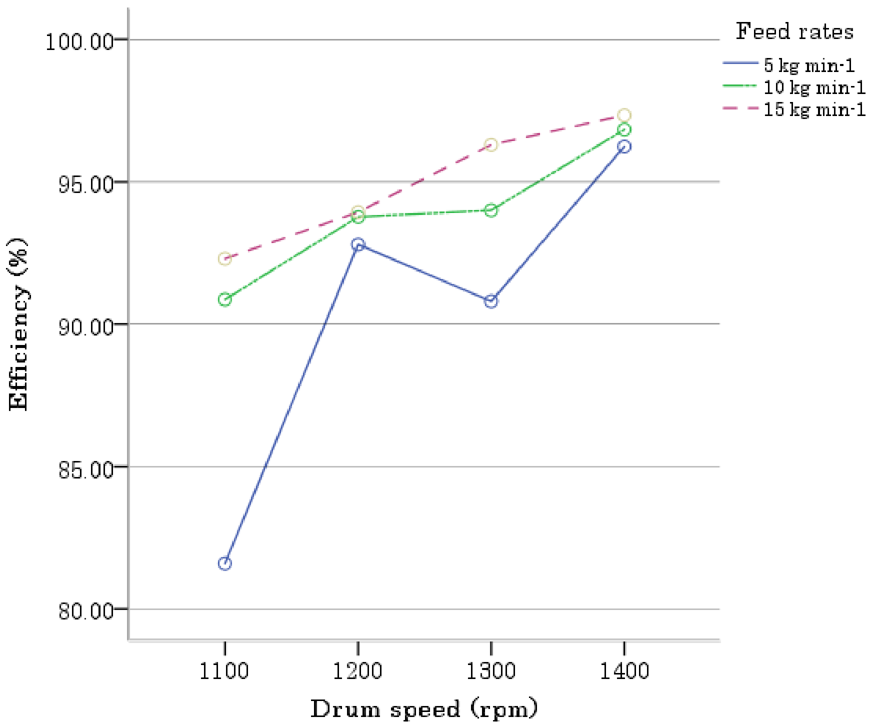

Figure 4*. Effect of drum speed and feed rate on grating efficiency.*

The highest grating efficiency of 97.3% was observed at a speed of 1400 r min^{-1} as well as feeding rate of 15 kg min^{-1}, while the lowest grating efficiency was 81.6% observed at a speed of 1100 r min^{-1} as well as feeding rate of 5 kg min^{-1}. The grating efficiency obtained in this study was higher compared to the value of 91.9% reported by Ndaliman (2006). In comparison, Esteves *et al.* (2019) reported an average grating efficiency of 91.56% at 1424.30 r min^{-1} while assessing a motor-operated grater. Ogunjirin *et al.* (2020) reported a grating efficiency of 84% at 78.4 r min^{-1} when grating cassava with a cassava grater. Malomo *et al.* (2014) reported a machine efficiency of 89.7% while assessing cassava grater.

Percentage of mechanical loss

Table 4 shows an analysis of variance for speed, feeding rate, as well as their interaction effect on mechanical loss of the grater. Based on the results shown in (Table 4), an analysis of variance showed that the speed, feeding rate, as well as interaction effect were significant at a 5% level since the p-value was lower than 0.05 ($P< 0.05$). According to the results, a machine's percentage of mechanical loss was influenced by the feed rate, operational drum speed, and interaction effect.

***Table 4**. Analysis variance for percentage loss of the grating machine.*

Source	DF	Sum of squares	Mean squares	F-value	P-value	Remark
Block	2	0.392	0.196			
Drum speed	3	357.243	119.081	136.81	0.0000	Significant
Feed rate	2	132.011	66.006	75.83	0.0000	Significant
Speed×Feed	6	120.575	20.096	23.09	0.0000	Significant
Error	22	19.150	0.870			
Total	35	629.371				

CV = 13.60, grand mean = 6.86, $P < 0.05$, significant at 5 % level, DF = degrees of freedom.

As shown in Figure 5 it was observed that the average percentage of mechanical loss of the machine ranged from 2.45% to 18.4%. With increasing drum speed from 1100 r min^{-1} to 1400 r min^{-1}, the percentage of mechanical loss decreased from 18.4% to 2.45%. The percentage of mechanical loss of the machine tended to decrease with an increase in speed as well as feeding rate. This means the percentage of mechanical loss had an inverse relationship to the speed as well as feed rate of cassava tuber.

The test results showed that as drum speed increased, the machine's percentage loss decreased. However, at 1300 r min^{-1} and at a feed rate of 5 kg min^{-1}, there was a sudden increase in loss was recorded when evaluating the grater at a feeding rate of 5 kg min^{-1}. A decrease in efficiency or low output was recorded when the drum rotated, returning the feeds back. Due to a decrease in efficiency or low output was obtained, leading to an increase in loss.

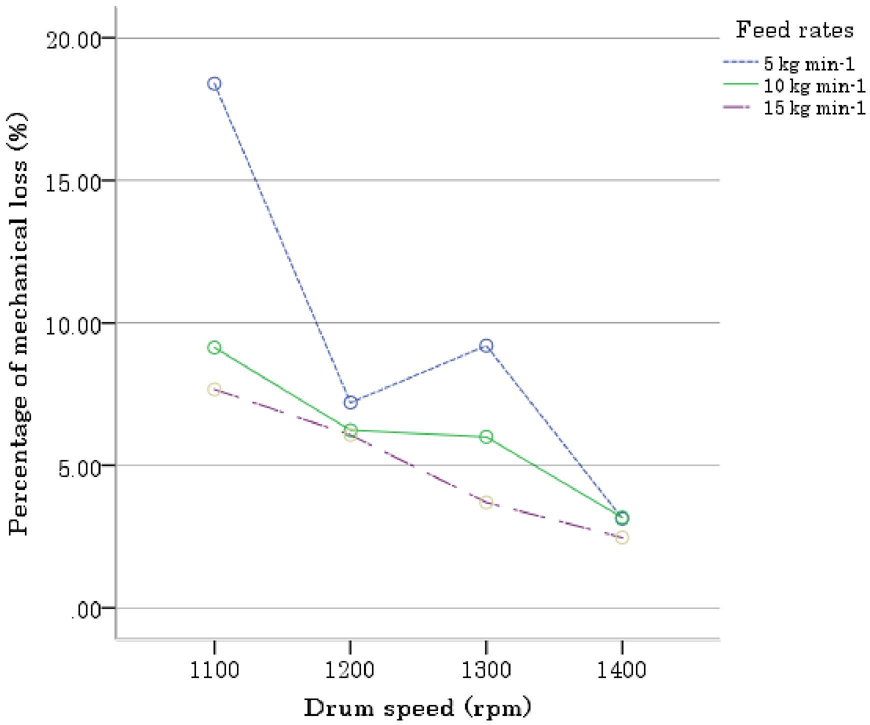

Figure 5. *Effect of speed and feed rate on mechanical loss*

The lowest percentage of mechanical loss of 2.45% was observed at a speed of 1400 r min^{-1} as well as feeding rate of 15 kg min^{-1}, while the highest percentage of mechanical loss was 18.4% observed at a speed of 1100 r min^{-1} as well as feeding rate of 5 kg min.$^{-1}$ Since the drum speed of 1400 r min^{-1} had the lowest percentage of loss among the other drum speed.

The percentage of mechanical loss recorded in this study was lower compared to the value of 8.45% at 1424.30 r min^{-1} reported by Esteves *et al.* (2019). In comparison, Ogunjirin *et al.* (2020) reported a percentage loss of 10.9% at 78.4 r min^{-1} when grating cassava with a cassava grater. Apodi *et al.* (2018) reported percentage loss of 5.5% when testing the performance of grater. Malomo *et al.* (2014) reported a loss of 10.3% while evaluating a grater.

Grating time

Table 5 shows the results for an analysis of variance for effect of speed, feeding rate, as well as interaction effect on the grating machine's grating time. Since the p value found in (Table 5) was less than 0.05 (P<0.05), an analysis of variance indicated that the speed, feeding rate, as well as interaction effect, were significant at a 5% level. Thus, the results suggested that a grating machine's grating time was influenced by the feed rate, drum speed, and interaction effect.

Table 5*. Analysis of variance for grating time of the grating machine.*

Source	DF	Sum of squares	Mean squares	F-value	P-value	Remark
Block	2	0.2	0.1			
Drum speed	3	6140.1	2046.7	390.98	0.0000	Significant
Feed rate	2	66256.2	33128.1	6328.37	0.0000	Significant
Speed×Feed	6	1005.4	167.6	32.01	0.0000	Significant
Error	22	115.2	5.2			
Total	35	73517.0				

CV = 2.35, grand mean = 97.50, $P < 0.05$, significant at 5 % level.

As shown in Figure 6 it was recorded that the average grating time of the machine ranged from 37 sec to 54 sec at a feeding rate of 5 kg min^{-1} with drum speeds of 1400 r min^{-1} as well as 1100 r min^{-1}. Generally, the results indicated (Figure 6) that the grating time of the machine tended to decrease with the increase of drum speed at the same feed rate because high drum speed had faster operated than lower drum speed which means grating time had an inverse relationship to the speed but a direct relationship to feed rate.

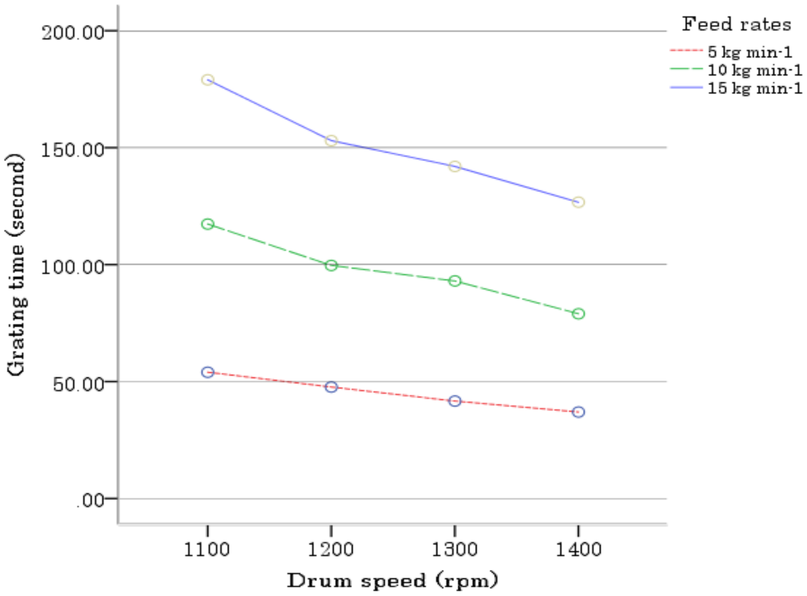

Figure 6*. Effect of drum speed and feeding rate on grating time*

The lowest grating time of 37 sec was observed at a speed of 1400 r min^{-1} as well as a feeding rate of 5 kg min^{-1}, while the highest grating time was 54 sec observed at a speed of 1100 r min^{-1} as well as a feeding rate of 5 kg min^{-1}. At the same feed rate, with increased drum speed from 1100 r min^{-1} to 1400 r min^{-1} grating time decreased from 54 sec to 37 sec.

Therefore, the drum speed of 1400 r min^{-1} was comparatively quick as well as might grate a tuber within a short period, there was also a drum speed that had the lowest grating time among the other drum speeds. A similar trend for cassava grating machines was reported by Esteves *et al.* (2019).

Quality performance efficiency

Table 6 shows an analysis of variance for speed, feeding rate, as well as interaction effect on the quality performance efficiency of machine. Depend on a result obtained

(Table 6), an analysis of variance revealed that a speed, feeding rate, as well as interaction effect were significant at a 5% level since the p value was lower than 0.05 ($P< 0.05$). The findings suggested that the quality performance efficiency of a grating machine was influenced by the drum speed, feed rate, and interaction effect.

***Table 6**. Analysis of variance for quality performance efficiency of the grating machine.*

Source	DF	Sum of squares	Mean squares	F-value	P-value	Remark
Block	2	1.292	0.6461			
Drum speed	3	85.135	28.3782	60.07	0.0000	Significant
Feed rate	2	162.865	81.4325	172.38	0.0000	Significant
Speed×Feed	6	21.905	3.6508	7.73	0.0001	Significant
Error	22	10.393	0.4724			
Total	35	281.589				

CV = 0.74, grand mean = 92.38, P < 0.05, significant at 5 % level.

As shown in Figure 7 it was founded that an average quality performance efficiency for grater ranged from 86.2% to 95.7%. With increased drum speed from 1100 r min^{-1} to 1400 r min^{-1}, quality performance efficiency increased from 86.2% to 95.7%. The results shown (Figure 7) that the quality performance efficiency of the machine tended to increase with increase of speed as well as feeding rate which implied quality performance efficiency had a direct relationship to the speed as well as feeding rate of cassava tuber.

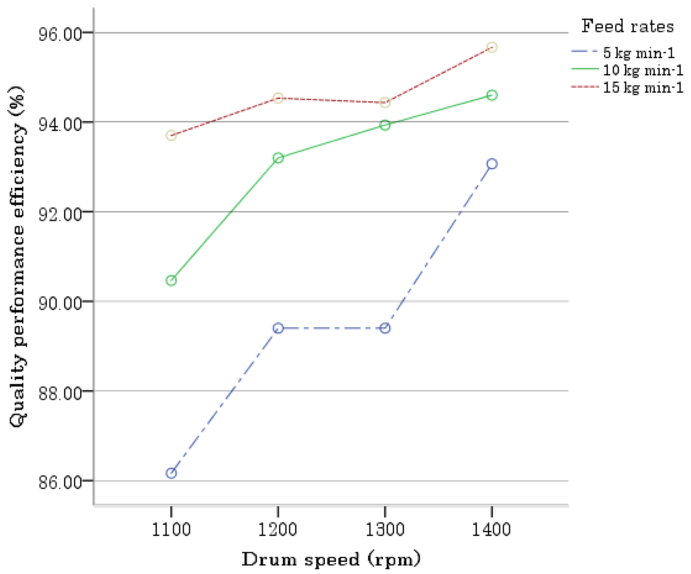

***Figure 7**. Effect of speed and feeding rate on quality performance efficiency.*

The highest quality performance efficiency of 95.7% was obtained at a speed of 1400 r min^{-1} as well as feeding rate of 15 kg min^{-1}, while the lowest quality performance efficiency was 86.2% obtained at a speed of 1100 r min^{-1} as well as feeding rate of 5 kg min^{-1}. In comparison, Ogunjirin *et al.* (2020) reported a quality performance efficiency of 92.23% at 78.4 r min^{-1} when grating cassava with a cassava grater. Malomo *et al.* (2014) reported a quality performance efficiency of 92.19% while evaluating a grater however the quality performance efficiency obtained in this study was higher.

Regression analysis

Regression analysis was conducted to predict how much variance was being accounted in the dependent variables by a set of independent variables. The regression analysis result for throughput capacity showed that 95% of throughput capacity was recorded both independent variables together, $F(2, 33) = 311.17$, $R = 0.974$, $p = 0.000$. The predicted throughput capacity was equal to $249.05 + 53.29V - 11.86F$. Also, regression analysis results for grating efficiency indicated that 70.14% of grating efficiency was accounted for by drum speed and feed rate together, $F(2, 33) = 38.77$, $R = 0.84$, $p = 0.000$. The predicted grating efficiency was equal to $82 + 2.58V + 2.30F$. Based on the regression analysis result, the percentage of mechanical loss showed that 70.1% of mechanical loss was contributed by drum speed and feed rate, $F(2, 33) = 38.76$, $R = 0.83$, $p = 0.000$. The estimated mechanical loss was equal to $18.03 - 2.66V - 2.25F$. Multiple linear regression analysis results showed that 82.8% of the quality performance efficiency was accounted for by drum speed and feed rate collectively, $F(2, 33) = 79.55$, $R = 0.91$, $p = 0.000$.

Economic cost analysis

The unit cost of an engine-operated cassava grating machine was determined by calculating the cost of different components and other costs. The costs of depreciation, interest on capital, fuel, and labor were computed as 2.8 EB h^{-1}, 2.5 EB h^{-1}, 20 EB h^{-1}, and 182 EB h^{-1} using the straight-line method. A payback period for the engine-powered cassava grating machine was calculated as 1.05 years. The benefit cost ratio was computed as 1:2.3 which showed grating cassava using the cassava grater was economical for cassava producers. The estimated cost of the one unit of an engine-operated cassava grating machine was determined as 44,046 EB.

Table 1. *Cost summary.*

Numbers	Cost parameters	Costs (ETB)
I	Material cost	31,880
II	Material wasted (2.5%)	797
III	Machinery cost	1,170
IV	Wage	870
V	Overhead 5% (III+IV)	102
VI	Profits 10% (I+II+III+IV+V)	3,481.9
VII	Sell taxation 15% (I+II+III+IV+V+VI)	5,745.1
Selling price		44,046

CONCLUSION

The performance of the cassava grating machine was conducted at four levels of speeds and three levels of feed rates at a moisture content of 52.9% for cassava tuber. The machine was operated at optimum conditions of rotational speeds, feeding loads, vibration, temperature, and proper adjustment in order to attain maximum capacity and efficiency. Some physical properties of cassava tuber for Hawassa varieties related to its use of grater were determined. The machine was evaluated in terms of throughput capacity, grating efficiency, mechanical loss, grating time, as well as quality performance efficiency. From test results, it was observed that with increasing drum speed from 1100 r min^{-1} to 1400 r min^{-1}, throughput capacity increased from 272.5 kg h^{-1} to 471.4 kg h^{-},[1] while grating efficiency increased from 81.6% to 97.3% and the percentage of mechanical loss decreased from 18.4% to 2.45%. According to an analysis of variance, the speed, feeding rate, also their interaction effects were found to be significant at the 5% level. The grating machine's dependent variables were all influenced by main and interaction effects. Multiple linear regression analysis was carried out to predict how much variance was being accounted for in the dependent variable by a set of drum speed and feed rate.

DECLARATION OF COMPETING INTEREST

The author of this manuscript declares that there is no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The author would like to declare that he solely developed all the sections.

ETHICS COMMITTEE DECISION

This article does not require any ethical committee decision.

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