# Investigation of a Motorised Integrated Cassava Slicing and Chopping Machine

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## Abstract

A study was carried out to investigate a motorised, integrated cassava tuber slicing and chopping machine. The integrated machine was investigated in terms of key performance metrics at three levels of speeds (950, 1150, and 1350 rpm for chopping; 300, 450, and 600 rpm for slicing) and two levels of feed rates (10 and 15 kg min$^{-1}$ for chopping; 5 and 10 kg min$^{-1}$ for slicing). According to the investigation findings, the maximum chopping capacity of 229.7 kg h$^{-1}$ was recorded at an operating speed of 1350 rpm and a feeding rate of 10 kg min$^{-1}$. The maximum chopping efficiency of 82.1% was obtained at an operating speed of 1350 rpm and a feeding rate of 15 kg min$^{-1}$, whereas the minimum mechanical loss of 9.06% was found at an operating speed of 1350 rpm and a feed rate of 15 kg min$^{-1}$. Based on the investigation results, at 600 rpm rotational speed and 5 kg min$^{-1}$ feed rate, the greatest slicer capacity of 114.8 kg h$^{-1}$ was noted. At 600 rpm rotational speed and 10 kg min$^{-1}$ feed rate, the greatest slicer efficiency of 71.6% was obtained. At this speed and feeding rate, the smallest loss of 11.06% was observed. Due to the low-key performance criteria recorded during the research, optimisation of the drum and hopper of the chopping unit, as well as the hopper and blade geometry of the slicing unit, is recommended.

**Keywords:** Capacity, Efficiency, Feed rate, Mechanical loss, Operating speed

## Introduction

Cassava (*Manihot esculenta*) is a starchy tuberous root crop, also known as yuca or manioc, that is a staple food in many tropical and subtropical regions. It is a woody shrub, grown for its edible, starchy, and tuberous roots. Cassava contributes to global food security, providing a staple carbohydrate source for about 500 million people, making it the third largest source of carbohydrates globally (Scaria, Pushparaj, Pappuswamy, Park, & Joseph, 2024). Cassava is a vital global food source, particularly in Africa (Adebayo, 2023). Global cassava production was over 300 million tonnes annually in recent years (Adebayo, 2023). Africa produces about 60% of the world's cassava, totalling nearly 200 million tonnes annually (Otekunrin, 2024). Cassava production in Ethiopia is concentrated in southern and southeastern regions, particularly the Wolaita and Gena Bosa districts (Zone & Sahle, 2024).

A major drawback of cassava is its high perishability as a crop, which can deteriorate within two or three days after harvesting, leading to significant post-harvest losses if not handled, processed, and stored properly (Uchechukwu-Agua, Caleb, & Opara, 2015). Post-harvest loss of cassava in Ethiopia can range from 13% to over 30%; figures of up to 50% are possible during specific storage periods (Parmar, 2018). It contains cyanogenic glucosides that must be properly processed to reduce or eliminate toxic levels of hydrogen cyanide before consumption (Ndubuisi & Chidiebere, 2018).

Cassava processing faces several technical, economic, and environmental challenges that limit product quality, efficiency, and large-scale production (Abass *et al.*, 2019). The main challenge is traditional processing methods, which are labour-intensive, time-consuming, and highly dependent on manual operations, leading to low throughput, inconsistent product quality, and significant material losses (Mikolo, Elenga, & Tsoumou, 2024). In addition, variability in tuber size, shape, and hardness complicates machine design and reduces processing efficiency. Limited access to affordable, energy-efficient mechanised equipment further constrains small- and medium-scale processors, particularly in developing regions (Mikolo *et al.*, 2024). Poor drying and storage facilities contribute to post-processing losses, microbial contamination, and reduced shelf life in cassava processing systems.

Presently, technology plays a vital role in agriculture, enhancing productivity, processing efficiency, and sustainability. It enables farmers to use resources more precisely, automate labour-intensive tasks, and make data-driven decisions, which helps increase yields while reducing waste or losses. The key innovations include precision agriculture, which is crucial for large-scale production due to the increasing demand for agricultural products.

The overall objective of this study was to substitute conventional cassava slicing and chopping with a machine in order to take away women's labour-intensive tasks in processing cassava effectively. Thus, this study aimed to investigate a motorised, integrated cassava slicing and chopping machine to generate performance metrics information for cassava growers in Ethiopia.

## Materials and Methods

### Materials

Different materials that were applicable during the investigation of an integrated cassava slicing and chopping machine were considered. The materials include a pocket meter, calliper, tachometer, receptacles, digital weight balance, angle of repose meter, stopwatch, and other apparatuses that were utilised to evaluate the integrated machine. The Qulle variety of cassava is used as the experiment's material.

### Methods

**Determination of selected physical properties of the Qulle variety of cassava**

Determining the physical properties of the cassava tuber is essential for designing, evaluating, and optimising agricultural machinery (Atsyo & Korkmaz, 2020). The physical properties of cassava are determined using a different method to aid in the design of processing and handling (Krishnakumar *et al.*, 2021). Physical properties, such as moisture content, bulk density, angle of repose, coefficient of friction, geometric mean diameter, arithmetic mean diameter, volume, surface area, porosity, sphericity, and shape factor, were selected.

**Determination of moisture content**

The moisture content was determined using the formula by Ndirika & Oyeleke (2006), as given in Equation 1.

$$Mc\,(wb)\,\% = \frac{M1 - M2}{M1} \times 100 \quad (1)$$

where $M_1$ is the initial mass of the test sample (g), $M_2$ is the final mass of the test sample (g), and $M_c$ is the moisture content of the cassava tuber.

**Determination of bulk density**

The bulk density of the cassava tuber was calculated using the following formula (Simonyan, 2016), given in Equation 2.

$$\rho_B = \frac{Mass\ of\ tuber}{Volume\ of\ tuber} \quad (2)$$

**Determination of the angle of repose**

The angle of repose was calculated by the formula given in Equation 3 (Simonyan, 2016).

$$Angle\,(\Theta) = tan^{-1}\frac{h}{d/2} \quad (3)$$

where $\Theta$ is the angle of repose in (°), $h$ is the height of the heap in (cm), and $d$ is the diameter of the heap in (cm).

**Determination of the geometric mean diameter**

The geometric mean diameter can be determined using Equation 4 (Udoji, Kaankuka, Awulu, & Igila, 2024).

$$GMD = \sqrt[3]{l \times b \times d} \quad (4)$$

where $GMD$ is geometric mean diameter (mm), $l$ is major length (mm), $b$ is breadth (mm), and $d$ is diameter (mm).

**Determination of the arithmetic mean diameter**

The arithmetic mean diameter of cassava

samples was determined using the formula (Udoji *et al*., 2024) in Equation 5.

$$AMD = \frac{(l+b+d)}{3} \quad (5)$$

where *AMD* is the arithmetic mean diameter (mm).

**Determination of porosity**

It can be determined by the expression as reported by Yunos & Ibrahim (2020), as given in Equation 6.

$$n = \frac{TD-\rho_B}{TD} \times 100 \quad (6)$$

where $n$ is porosity, $T_D$ is true density, and $\rho_B$ is bulk density.

**Determination of sphericity**

The sphericity of cassava tuber samples was determined using the formula by Simonyan (2016), as given in Equation 7.

$$\Phi = \frac{\sqrt[3]{lbd}}{l} \quad (7)$$

where $\Phi$ is the sphericity (mm), $l$ is the major length (mm), $b$ is the breadth (mm), and $d$ is the diameter (mm).

**Procedures for conducting experiments**

The Qulle variety of cassava was manually peeled with knives and rinsed with water for hygienic reasons before being weighed in sets of 5 kg, 10 kg, for slicing operation, and 10 kg and 15 kg for chopping operation for each operating speed. After starting the machine, a digital tachometer was used to set the speed to 950, 1150, and 1350 rpm for chopping operation, as well as 300, 450, and 600 rpm for slicing operation (Adewale, Raji, & Sedara, 2023). The investigation of the machine needed 225 kg for the chopping operation and 225 kg for the slicing operation, a total of 450 kg of Qulle variety, which could be used for the entire test run.

**Investigation of the performance metrics of the integrated machine**

The investigation of the integrated slicing and chopping machine was conducted based on key performance metrics like the machine's throughput capacity, machine efficiency, and mechanical loss, with results being significantly influenced by variables such as operating speed, material feed rate, and moisture content (Wanjala, 2023). The performance metrics, such as chopping capacity, chopping efficiency, mechanical loss, as well as slicing throughput capacity, slicing efficiency, and percentage of loss, were calculated using the formulas by Precoppe (2021) as follows:

$$\text{Chopping capacity (kg h}^{-1}\text{)} = \frac{Total\ Mass\ of\ cassava\ tubers\ chopped\ (kg)}{Time\ taken\ to\ chop\ tuber\ (hr)} \quad (8)$$

$$\text{Chopping efficiency (\%)} = \frac{Mass\ of\ cassava\ tuber\ chopped\ (kg)}{Mass\ of\ tuber\ fed\ into\ the\ machine\ (kg)} \times 100 \quad (9)$$

$$Mechanical\ loss = \frac{Total\ mass\ fed\ (kg) - total\ mass\ collected (kg)}{Total\ mass\ fed\ (kg)} \times 100 \quad (10)$$

$$\text{Slicer throughput capacity (kg h}^{-1}\text{)} = \frac{Weight\ of\ sliced\ cassava\ tuber\ (kg)}{Time\ taken\ to\ slice\ cassava\ (hr)} \quad (11)$$

$$\text{Slicer efficiency} = \frac{Weight\ cassava\ collected\ (kg) - weight\ non\ uniform\ tuber\ slice (kg)}{Weight\ of\ cassava\ collected\ (kg)} \times 100 \quad (12)$$

$$\text{Percentage of loss} = \frac{Weight\ of\ cassava\ feed\ (kg) - Weight\ of\ cassava\ collected\ (kg)}{Weight\ of\ cassava\ feed\ (kg)} \times 100 \quad (13)$$

**Fig. 1.** The integrated machine and a sample of chopped cassava

**Fig. 2.** Sliced cassava during current investigation

**Experimental design and data analysis**

The experiment was carried out using a randomised block factorial design with operating speed as a controlled factor, and the levels of operating speed and feed rate taken as experimental treatments. Statistical analysis of collected data was performed using Statistix 8 software. Confidence intervals of 95% were used to show the significant effect of the independent variable on the dependent variable. The mean separation between treatment means was conducted by the least significant difference at a 5% level. The data were subjected to analysis of variance by following the applicable technique for the design of the experiment.

## Results and Discussion

**Characteristics of the Qulle variety of cassava**

Table 1 illustrates the means, standard deviations (STDEV), and coefficients of variation (CV%) of some selected physical properties of the Qulle variety of cassava tuber samples. The findings confirmed that the Qulle variety of cassava tubers had a mean moisture content of 55.8% on a wet basis, with a standard deviation of 1.07, resulting in an average mean value of 55.8±1.07. The value of this moisture content ranged from 55.2 % to 57.1%. The results revealed that the Qulle variety of cassava had a bulk density ranging from 2.54 to 2.79 g $cm^{-3}$. The mean density was found to be 2.63 g cm-3, with a standard deviation of 0.14. The Qulle variety of cassava had an angle of repose that varied from 27.4° to 29.5°, with a mean of 28.2° and a standard deviation of 1.14. The same pattern for a physical property of cassava tuber was reported by Simonyan (2016).

From the determination of properties, the results revealed that the geometric mean diameter of the Qulle variety of cassava tubers varied from 14.06 mm to 16.2 mm. 14.78 mm and 1.23 were determined to be the mean value and standard deviation, respectively, with an average mean value (amv) of 14.78±1.23. The arithmetic mean diameter ranged from 12.1 mm to 13.8 mm. 12.86 mm and 0.86 were obtained as the mean value and standard deviation. The porosity of the Qulle variety of cassava tubers ranged from 0.37 to 0.39, and the porosity was computed to have a mean of 0.38 and a standard deviation of 0.01. The Qulle variety of cassava tubers had a sphericity ranging from 0.97 to 0.99, with a mean and standard deviation of 0.98 and 0.01, and an average mean value (amv) of 0.98±0.01, respectively. This study's findings are related to previous research conducted by Simonyan (2016).

**Table 1-** Characteristics of the Qulle variety of cassava

| Parameters | Mean values | Standard deviation | Mean±STDEV | Coefficient of variation |
|---|---|---|---|---|
| Moisture content (%) | 55.8 | 1.07 | 55.8±1.07 | 1.91 |
| Bulk density (g cm$^{-3}$) | 2.63 | 0.14 | 2.63±0.14 | 5.28 |
| Angle of repose (°) | 28.2 | 1.14 | 28.2±1.14 | 4.03 |
| Coefficient of friction (wood) | 0.60 | 0.04 | 0.60±0.04 | 6.86 |
| Coefficient of friction (mild steel) | 0.54 | 0.043 | 0.54±0.04 | 8.07 |
| Coefficient of friction (Aluminum) | 0.35 | 0.03 | 0.35±0.03 | 7.56 |
| Geometric mean diameter (mm) | 14.78 | 1.23 | 14.78±1.23 | 8.32 |
| Arithmetic mean diameter (mm) | 12.86 | 0.86 | 12.86±0.86 | 6.7 |
| Unit volume (cm$^3$) | 506.33 | 26.27 | 506.33±26.27 | 5.12 |
| Surface area (mm$^2$) | 6485.7 | 326.03 | 6485.7±326.03 | 5.02 |
| Porosity (%) | 0.38 | 0.01 | 0.38±0.01 | 3.69 |
| Sphericity | 0.98 | 0.01 | 0.98±0.01 | 1.02 |

The results obtained from the physical properties of the fresh Qulle variety of cassava tubers indicate characteristics that are consistent with a high-moisture root crop. The mean moisture content confirms that fresh cassava tubers contain substantial internal water, which strongly influences their mechanical behaviour, storability, and processing requirements. The observed angle of repose indicates moderate flowability, implying that cassava tubers can flow reasonably well under gravity. This is advantageous in the design of hoppers and chutes, where excessive angles could hinder material movement. The bulk density suggests that the tubers possess considerable mass relative to their volume. This property is significant for the design of systems and equipment, as higher bulk density affects load calculations and structural requirements of the machine.

The coefficient of friction reflects a high resistance to sliding on contact surfaces, likely influenced by the rough and irregular outer surface of the tubers as well as their moisture content. The geometric mean diameter and arithmetic mean diameter, along with the measured unit volume and surface area, indicate variability in tuber size and shape. The porosity indicates moderate void spaces when tubers are packed together, which is beneficial for aeration during storage but may reduce packing efficiency. The high sphericity suggests that the cassava is nearly spherical in shape. High sphericity is generally favourable for uniform rolling, improved flow behaviour, and predictable interactions with mechanical components. The measured properties provide essential data for the efficient design, optimisation and testing of cassava processing machines (Abdulrasak, 2024).

**Investigation of key performance metrics**

**Chopping capacity**

Analysis of variance for the impact of operating speed, feed rate, and the interaction effect on the chopping capacity of the machine is presented in Table 2. The analysis of variance indicates that the main effects of operating speed and feed rate, and the interaction effect, were significant at the 5% level (Table 2), as the P-values were less than 5%. The results revealed that the chopping capacity of a chopping machine was influenced by machine speed, feeding rate, and the interaction effect, as indicated in Table 2.

**Table 2-** ANOVA for the chopping capacity of the chopping machine

| Source of variation | Degrees of freedom | F-value | P-value |
|---|---|---|---|
| Replication | 2 | | |
| Operating speed ($S_o$) | 2 | 319.27 | 0.00 |
| Feeding rate ($F_r$) | 1 | 10.73 | 0.00 |
| Interaction effect ($S_o \times F_r$) | 2 | 6.87 | 0.01 |
| Error | 10 | | |
| Total | 17 | | |
| Grand mean | 164.72 | | |
| CV | 3.97 | | |

P < 0.05, significant at 5 % level, P > 0.05, non-significant at 5 % level.

Based on the investigation results, the maximum chopping capacity of 229.7 kg $h^{-1}$ was recorded at an operating speed of 1350 rpm and a feed rate of 10 kg $min^{-1}$, whereas the minimum chopping capacity was 119.9 kg $h^{-1}$, recorded at an operating speed of 950 rpm and a feed rate of 15 kg $min^{-1}$. Therefore, the mean chopping capacity of the machine varied from 119.9 kg $h^{-1}$ to 229.7 kg $h^{-1}$ with increasing operating speed from 950 rpm to 1350 rpm, and the chopping capacity increased from 119.9 kg $h^{-1}$ to 229.7 kg $h^{-1}$.

The results indicate that the interaction between operating speed and feed rate has a strong influence on chopping capacity. The maximum chopping capacity achieved at an operating speed with a feed rate suggests that higher rotational speeds enhance the chopping and material conveyance capability of the chopper. In contrast, the minimum chopping capacity recorded at 950 rpm and a higher feed rate indicates that low operating speeds may be inadequate to handle increased material input. The chopping mechanism may experience overloading, leading to incomplete chopping, material accumulation, and reduced throughput. Overall, the study emphasises that operating speed plays a more dominant role than feed rate in determining chopping capacity and that optimal performance is achieved when both parameters are properly matched. Figure 3 shows that the chopping capacity of the machine increases with operating speed and decreases with feed rate. This indicates that chopping capacity has a direct relationship with operating speed and an inverse relationship with the experimental material, which in this case is the cassava tuber. This study's finding is lower than the results of previous research conducted by Seth (2020).

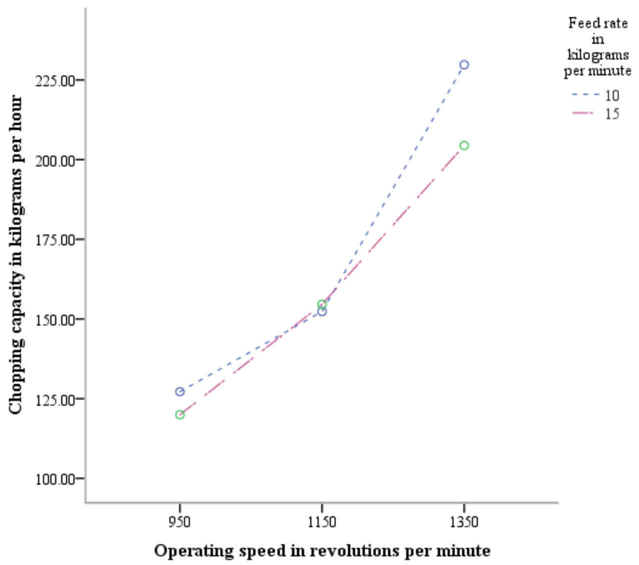


**Fig. 3.** The impact of operating speed and feeding rate on the chopping capacity

**Chopping efficiency**

Table 3 shows the analysis of variance for the main effects of operating speed, feed rate, and the interaction effect on the chopping efficiency of the machine. Analysis of variance revealed that both operating speed and feed rate significantly affected the results at a 5% significance level, as indicated by a P-value lower than 0.05 in Table 3. However, the combined effect of these two factors was not significant at the same level. Operating speed and feed rate significantly affect a machine's chopping efficiency, although their combined effect does not.

**Table 3-** ANOVA for the chopping efficiency of the chopping machine

| Source of variation | Degrees of freedom | F-value | P- value |
|---|---|---|---|
| Replication | 2 | | |
| Operating speed ($S_r$) | 2 | 19.34 | 0.00 |
| Feeding rate ($F_r$) | 1 | 5.31 | 0.04 |
| Interaction effect ($S_r \times F_r$) | 2 | 2.37 | 0.14 |
| Error | 10 | | |
| Total | 17 | | |
| Grand mean | 80.159 | | |
| CV | 1.13 | | |

$P < 0.05$, significant at 5 % level, $P > 0.05$, non-significant at 5 % level.

From the investigation, the maximum chopping efficiency of 82.1% was obtained at an operating speed of 1350 rpm and a feed rate of 15 kg $min^{-1}$, whereas the minimum chopping efficiency was 78.5% detected at an operating speed of 950 rpm and a feed rate of 10 kg $min^{-1}$. It was observed that the mean chopping efficiency of the machine varied from 78.5% to 82.1% with increasing operating speed from 950 rpm to 1350 rpm.

The results of the investigation indicate that chopping efficiency was strongly influenced by both operating speed and feed rate. The efficiency at higher speeds can be attributed to the increased chopping frequency and impact force of the chopping drum, which enhanced material fragmentation and reduced the occurrence of unchopped or partially chopped residues. The higher feed rate at this speed likely ensured a continuous and uniform flow of material into the chopping drum, promoting effective drum and material interaction. In contrast, at reduced speeds, the chopping action becomes less aggressive, leading to incomplete chopping due to unprocessed material. The lower feed rate may have further contributed to inefficiencies by causing irregular material flow, which can result in inconsistent contact between the drum and the cassava tuber. Overall, the observed trend suggests that increasing operating speed and feed rate within the tested range enhances chopping efficiency.

The results shown in Figure 4 indicate that the chopping efficiency of the machine tended to increase with the increase of operating speed and feeding rate, which means chopping efficiency had a direct relationship with the operating speed and feeding rate of experimental material (Qulle variety of cassava tuber). The previous studies in the literature relating to these findings are reported by Bolaji, Adejuyigbe, and Ayodeji (2008).

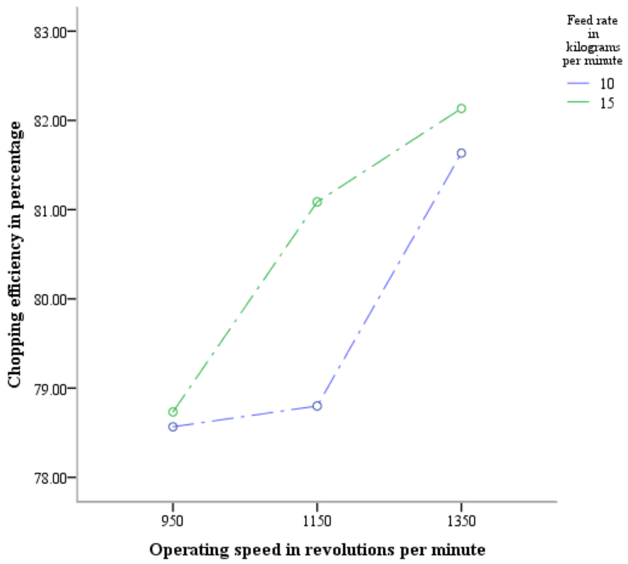


**Fig. 4.** The impact of operating speed and feed rate on chopping efficiency

## Mechanical loss

Analysis of variance for the impact of operating speed, feed rate, and the interaction effect on the mechanical loss of the machine is presented in Table 4. The analysis of variance presented in Table 4 showed that both operating speed and feed rate had a significant main effect at the 5% level, as indicated by a P-value less than 0.05. In contrast, the interaction effect between these two factors was not significant, as the P-value was greater than 0.05. Based on the findings, the chopper's mechanical loss was influenced by the main effects, but it was not affected by the interaction effects.

**Table 4-** ANOVA for the mechanical loss of the chopping machine

| Source of variation | Degrees of freedom | F-value | P- value |
|---|---|---|---|
| Replication | 2 | | |
| Operating speed ($S_o$) | 2 | 19.31 | 0.00 |
| Feeding rate ($F_r$) | 1 | 5.42 | 0.04 |
| Interaction effect ($S_o \times F_r$) | 2 | 2.39 | 0.14 |
| Error | 10 | | |
| Total | 17 | | |
| Grand mean | 11.037 | | |
| CV | 8.20 | | |

P < 0.05, significant at 5 % level, P > 0.05, non-significant at 5 % level.

The investigation findings revealed that the minimum mechanical loss was 9.06% at an operating speed of 1350 rpm with a feed rate of 15 kg $min^{-1}$. In contrast, the maximum mechanical loss was 12.6%, observed at an operating speed of 950 rpm and a feed rate of 10 kg $min^{-1}$. Overall, the mean mechanical loss of the machine ranged from 9.06% to 12.6% as the operating speed increased from 950 rpm to 1350 rpm, demonstrating a reduction in mechanical loss from 12.6% to 9.06%.

The investigation indicates a clear influence of both operating speed and feed rate on mechanical loss. This suggests that the system operates more efficiently under these conditions. At higher speeds, frictional and transmission losses are distributed over a greater useful output. In contrast, the maximum mechanical loss recorded at a lower speed and a reduced feed rate can be attributed to inefficient energy transfer and increased relative frictional effects. Under low-speed and low-feed conditions, a larger portion of the input energy is dissipated in overcoming resistances rather than contributing to productive work. Overall, the results demonstrate that increasing both operating speed and feed rate within the tested range improves efficiency by minimising losses, highlighting the importance of optimal parameter selection for efficient system performance.

As shown in Figure 5, the operating speed of 1350 rpm resulted in the lowest loss compared to other operating speeds, as confirmed by the investigation of the machine. The results indicate that the mechanical loss of the machine tends to decrease with increasing operating speed and feed rate. This demonstrates that there is an inverse relationship between mechanical loss and both operating speed and the experimental material used. The comparable funding pattern for a machine was reported by Malomo & State (2015).

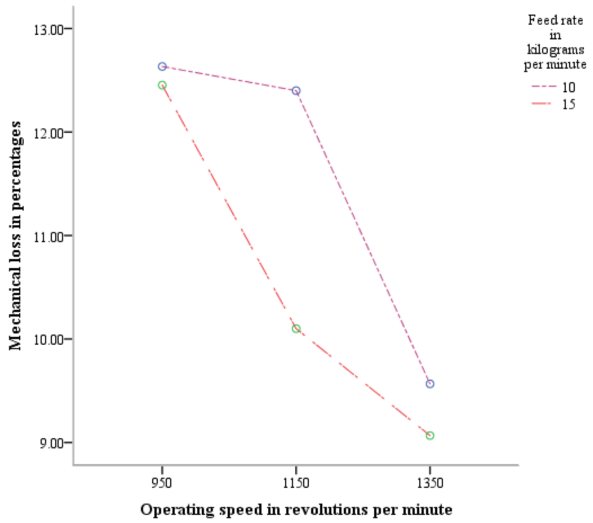


**Fig. 5.** The impact of operating speed and feed rate on the mechanical loss

The integrated machine for chopping operation was investigated in terms of key performance metrics, such as chopping capacity, chopping efficiency, and mechanical loss at three levels of operating speeds and two levels of feeding rate, at a moisture content of 55.8% for the Qulle variety of cassava. After the chopper completed its operation, the data was recorded, including details such as the output, chopping time, and the amount of unchopped tubers, along with other relevant information. During the investigation, it was observed that a cassava tuber fed into the machine was chopped; however, there was a risk of tubers falling back out of the hopper upon contact with the drum. The investigation revealed that the design of the hopper was flawed, causing some product to drop from the machine before it could be chopped, which resulted in a loss of the chopped output.

**The average differences between treatment means for the chopping operation**

The least significant difference (LSD) all pairwise comparisons test was conducted on chopping capacity, chopping efficiency, and mechanical loss for each treatment, as presented in Table 5. This analysis involved a least significant difference (LSD) all pairwise comparisons test of dependent variables across three operating speeds and two feeding rates in order to identify significant differences among the treatment means.

**Table 5-** Comparisons between treatment means for the chopping operation

| No. | Treatment combination | Operating Speeds (rpm) | Feeding rate (kg min$^{-1}$) | Chopping capacity (kg h$^{-1}$) | Chopping efficiency (%) | Mechanical loss (%) |
|---|---|---|---|---|---|---|
| 1 | $S_o1F_r1$ | 950 | 10 | 127.19$^d$ | 78.56$^b$ | 12.63$^a$ |
| 2 | $S_o1F_r2$ | 950 | 15 | 119.97$^d$ | 78.73$^b$ | 12.45$^a$ |
| 3 | $S_o2F_r1$ | 1150 | 10 | 152.37$^c$ | 78.80$^b$ | 12.40$^a$ |
| 4 | $S_o2F_r2$ | 1150 | 15 | 154.60$^c$ | 81.08$^a$ | 10.10$^b$ |
| 5 | $S_o3F_r1$ | 1350 | 10 | 229.77$^a$ | 81.63$^a$ | 9.567$^b$ |
| 6 | $S_o3F_r2$ | 1350 | 15 | 204.43$^b$ | 82.13$^a$ | 9.06$^b$ |

$S_o$ = Operating Speed, $F_r$ = Feeding rate and CV = Coefficient of variation

The least significant difference (LSD) all pairwise comparisons test indicated that there were four distinct groups (a, b, c, and d) for the test of chopping capacity in the treatment. For the test of chopping efficiency in the treatment, there were two groups (a and b). Similarly, for the test of mechanical loss in the treatment, there were also two groups (a and b). Within these groups, the treatment means were not significantly different from one another at the 5% level, based on the LSD all pairwise comparisons test.

Analysis of variance for the effect of rotational speed, feed rate, and their interaction on the slicer throughput capacity is presented (Table 6). According to the results found, the analysis of variance indicated that the effect of rotational speed, feed rate, and interaction was significant at the level of five percent (5%) as a result of the values for P were smaller than 0.05 ($P< 0.05$). The outcomes demonstrated that rotational speed, feed rate, and interaction influenced a slicer's throughput capacity, as illustrated in Table 6.

**Slicer throughput capacity**

**Table 6-** ANOVA for the slicer throughput capacity for the slicing operation

| Source of variation | Degrees of freedom | F-value | P- value |
|---|---|---|---|
| Replication | 2 | | |
| Rotational speed ($S_r$) | 2 | 319.27 | 0.00 |
| Feeding rate ($F_r$) | 1 | 10.73 | 0.00 |
| Interaction effect ($S_r \times F_r$) | 2 | 6.87 | 0.01 |
| Error | 10 | | |
| Total | 17 | | |
| Grand mean | 82.361 | | |
| CV | 3.97 | | |

$P < 0.05$, significant at 5 % level, $P > 0.05$, non-significant at 5 % level

Based on the findings of the investigation, the highest slicer throughput capacity of 114.8 kg h$^{-1}$ was observed at a rotational speed of 600 rpm and a feed rate of 5 kg min$^{-1}$.

Conversely, the lowest throughput capacity was noted at a rotational speed of 300 rpm and a feed rate of 10 kg $min^{-1}$. Overall, the slicer throughput capacity varied between 59.9 kg $h^{-1}$ and 114.8 kg $h^{-1}$. The results indicated that the throughput capacity was significantly affected by the interaction between the rotational speed and the feed rate.

This indicates that higher rotational speeds enhance slicing capacity by increasing the frequency of slicing actions within a given time. At this operating condition, the slicer likely achieved an optimal balance between speed and material handling, allowing for smooth and continuous slicing without excessive material accumulation. Conversely, this reduction in throughput may be attributed to the inability of the slicer mechanism to effectively process the increased material input at reduced cutting speeds. Excess feed at lower rotational speeds can lead to incomplete slicing or increased resistance within the slicing chamber, ultimately lowering the effective throughput. Overall, the results underscore the importance of selecting appropriate operational parameters to enhance slicer capacity and provide valuable guidance for optimising slicer design and operation in processing applications.

As illustrated in Figure 6, the throughput capacity of the slicer increased as the rotational speed rose from 300 rpm to 600 rpm. However, while the rotational speed increased, the throughput capacity generally continued to rise, and the

feed rate began to decline. Based on the result, the slicer throughput capacity was inversely associated with the feed rate of the Qulle variety of cassava tubers and directly associated with the rotational speed of the machine. This study's findings are lower than those of Girma, Moges, and Kidanemariam (2024).

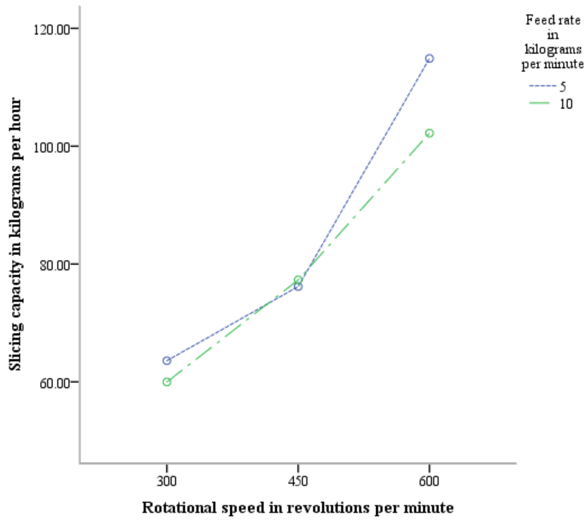


**Fig. 6.** The impact of rotational speeds and feeding rates on the slicer throughput capacity

**Slicer efficiency**

Analysis of variance for the effects of rotational speed, feed rate, and interaction on slicer efficiency is presented in Table 7. The analysis of variance indicated that both rotational speed and feed rate had a significant effect on slicer efficiency at the five percent level, as the p-values obtained were lower than 0.05. However, the interaction effect between these two factors was found to be non-significant. Therefore, the results suggest that slicer efficiency is influenced by rotational speed and feed rate independently, rather than through their combined effect.

**Table 7-** ANOVA for the slicer efficiency for the slicing operation

| Source of variation | Degrees of freedom | F-value | P- value |
|---|---|---|---|
| Replication | 2 | | |
| Rotational speed ($S_r$) | 2 | 19.34 | 0.00 |
| Feeding rate ($F_r$) | 1 | 5.31 | 0.04 |
| Interaction effect ($S_r \times F_r$) | 2 | 2.37 | 0.14 |
| Error | 10 | | |
| Total | 17 | | |
| Grand mean | 69.659 | | |
| CV | 1.3 | | |

$P < 0.05$, significant at 5 % level, $P > 0.05$, non-significant at 5 % level.

The investigation results showed that the highest slicer efficiency of 71.6% was achieved at a rotational speed of 600 rpm and a feed rate of 10 kg $min^{-1}$. In contrast, the lowest slicer efficiency of 68.06% was recorded at a rotational speed of 300 rpm and a feed rate of 5 kg $min^{-1}$. It was revealed that the slicer's efficiency ranged from 68.06% to 71.6%. The results of the investigation indicate that both rotational speed and feed rate have a measurable influence on slicer efficiency. This trend suggests that increasing both rotational speed and feed rate within the tested range enhances the overall performance of the slicer. At higher rotational speeds, the cutting blades interact more frequently with the material, resulting in smoother and more continuous slicing. This reduces idle time and minimises incomplete cuts, thereby improving efficiency. Similarly, a higher feed rate ensures a more consistent supply of material to the slicing mechanism, allowing the machine to operate closer to its optimal capacity and reducing losses associated with underutilisation. Conversely, the lower efficiency may be attributed to insufficient blade speed and limited material flow. Under these conditions, the slicer likely experiences intermittent cutting and increased resistance, leading to less effective energy utilisation and reduced slicing performance.

As demonstrated in Figure 7, the slicer efficiency increased as the rotational speed rose from 300 rpm to 600 rpm. The efficiency of the slicer generally increases with higher rotational speeds and feed rates. It demonstrated that a direct association exists between the rotational speed and feed rate of the Qulle variety of cassava tuber and the slicer efficiency. Previous studies related to these results were reported by Bolaji, Adejuyigbe, Ekiti, and Ayodeji (2008).

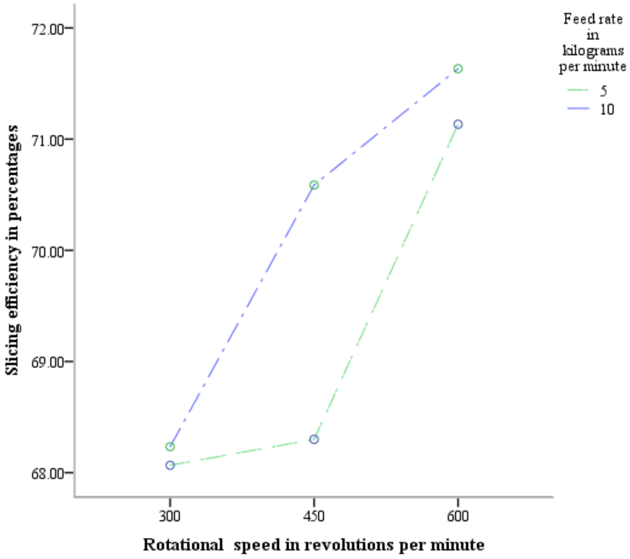


**Fig. 7.** The impact of rotational speeds and feeding rates on the slicer efficiency

**Percentage of loss**

Analysis of variance for the effect of rotational speed, feeding rate, and interaction on the slicer percentage of loss is presented in Table 8. The analysis of variance results indicated that both rotational speed and feeding rate had a significant effect on the percentage loss of the machine during the slicing operation, as evidenced by a P-value lower than 0.05. However, the interaction effect between these two factors was not significant, with a P-value greater than 0.05. This suggests that while feeding rate and rotational speed influence the machine's performance, their combined effect does not.

**Table 8-** ANOVA for the percentage loss for the slicing operation

| Source of variation | Degrees of freedom | F-value | P- value |
|---|---|---|---|
| Replication | 2 | | |
| Rotational speed ($S_r$) | 2 | 19.31 | 0.00 |
| Feeding rate ($F_r$) | 1 | 5.42 | 0.04 |
| Interaction effect ($S_r \times F_r$) | 2 | 2.39 | 0.14 |
| Error | 10 | | |
| Total | 17 | | |
| Grand mean | 13.037 | | |
| CV | 6.94 | | |

$P < 0.05$, significant at 5 % level, $P > 0.05$, non-significant at 5 % level.

Based on the investigation results, the smallest percentage loss observed was 11.06% at a rotational speed of 600 rpm and a feeding rate of 10 kg $min^{-1}$. In contrast, the largest percentage loss was 14.6% at a rotational speed of 300 rpm and a feeding rate of 5 kg $min^{-1}$. Therefore, the percentage of loss ranged from 11.06% to 14.6%. The results of the investigation indicate that both rotational speed and feeding rate significantly influence percentage loss. This trend suggests that increasing both rotational speed and feed rate contributes to reduced material loss. The reduction in percentage loss at higher rotational speeds may be attributed to improved material handling and more effective processing, which minimises stagnation and incomplete separation. Similarly, a higher feeding rate likely ensures a more continuous material flow, reducing exposure time to inefficiencies that can lead to losses. Overall, the findings demonstrate a clear interaction between rotational speed and feeding rate, where optimal combinations enhance system performance.

As Figure 8 demonstrates, the percentage of loss reduced as the rotational speed rose from 300 rpm to 600 rpm. By way of rotational speed and feed rate, the percentage of loss was once expected to decline as well. It demonstrated that the rotational speed and feed rate (Qulle variety of cassava tuber) had a reverse association with the loss. A comparable pattern for the machine was reported by Girma *et al*. (2024).

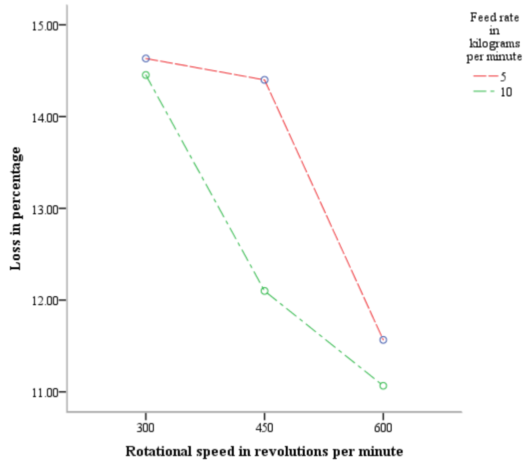


**Fig. 8.** The impact of rotational speeds and feeding rates on the percentage of loss

The integrated machine for slicing operation was investigated at three rotational speeds (300, 450, and 600 rpm) as well as two feed rate levels (5 kg and 10 kg) with respect to performance metrics, including slicer throughput capacity, slicer efficiency, and percentage of loss. Once the slicing operation was finished, mass measurements were made for the sliced tuber and the time taken for each experimental run. The investigation demonstrates that the machine processes cassava into slices with a thickness ranging from 3 to 5 mm for all feed amounts of tubers. The slicer's performance in slicing the Qulle variety of cassava was neither impressive nor low, depending on the test results; it needs major improvements in the slicer's hopper and blade geometry.

**Mean separations of treatment means for the slicing operation**

The mean separations of the treatment mean of slicing capacity, slicing efficiency and percentage of loss were conducted for each treatment, as given in Table 9. Then, this analysis was subjected to the least significant difference (LSD) all pairwise comparisons test of dependent variables for levels of rotational speeds and levels of feed rates to determine significant differences among treatment means.

**Table 9-** Comparisons between treatment means for the slicing unit operation

| No. | Treatment combination | Rotational Speeds (rpm) | Feeding rate (kg min$^{-1}$) | Slicing capacity (kg h$^{-1}$) | Slicing efficiency (%) | Percentage of loss (%) |
|---|---|---|---|---|---|---|
| 1 | $S_r1F_r1$ | 300 | 5 | 63.60$^d$ | 68.06$^b$ | 14.63$^a$ |
| 2 | $S_r1F_r2$ | 300 | 10 | 59.98$^d$ | 68.23$^b$ | 14.45$^a$ |
| 3 | $S_r2F_r1$ | 450 | 5 | 76.18$^c$ | 68.30$^b$ | 14.40$^a$ |
| 4 | $S_r2F_r2$ | 450 | 10 | 77.30.$^c$ | 70.58$^a$ | 12.10$^b$ |
| 5 | $S_r3F_r1$ | 600 | 5 | 114.88$^a$ | 71.13$^a$ | 11.56$^b$ |
| 6 | $S_r3F_r2$ | 600 | 10 | 102.22$^b$ | 71.63$^a$ | 11.06$^b$ |

$S_r$ = Rotational Speed, $F_r$ = Feeding rate and CV = Coefficient of variation

So, the least significance difference all pairwise comparisons test (Table 9) showed that there were 4 groups (a, b, c, and d) for test of slicing treatment capacity, for test of slicing efficiency for treatment, there are 2 groups (a and b), and for test of percentage of loss for treatment, there are 2 groups (a and b) in which the treatment means were not significantly different from one another at 5% level in all cases based on least significance difference (LSD) all pairwise comparisons test.

## Conclusion

The integrated machine for chopping and slicing operations was investigated in terms of key performance metrics at three levels of speeds and two levels of feeding rate at a moisture content of 55.8% for the Qulle variety of cassava tuber. From the determination of properties, the findings verified that the Qulle variety of cassava tubers' mean moisture content, bulk density, angle of repose, geometric mean diameter, arithmetic mean diameter, unit volume, surface area, porosity, and sphericity were found to be 55.8%, 2.63 g $cm^{-3}$, 28.2°, 14.78 mm, 12.86 mm, 506.33 $cm^3$, 6485.7 $mm^2$, 0.38, and 0.98, respectively. According to the investigation findings, with increasing operating speed from 950 rpm to 1350 rpm, the chopping capacity increased from 119.9 kg $h^{-1}$ to 229.7 kg $h^{-1}$; the chopping efficiency increased from 78.5% to 82.1%, and the mechanical loss reduced from 12.6% to 9.06%. In accordance with the investigation results, as the rotational speed rose from 300 rpm to 600 rpm, the slicer throughput capacity rose from 59.9 kg $h^{-1}$ to 114.8 kg $h^{-1}$, the slicer efficiency increased from 68.06% to 71.6%, and the percentage of loss reduced from 14.6% to 11.06%. Based on the analysis of variance results, the main effect of speed and feed rate could influence the capacity, efficiency, and loss of a machine; however, the interaction effect did not influence efficiency and loss, but it did affect the capacity of the machine in both chopping and slicing operations. The study found that the integrated machine required optimisation interventions for both the drum and hopper of the chopping unit, as well as for the hopper and blade geometry of the slicing unit. This need arose because the key performance metrics recorded during the investigation were low.

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# بررسی دستگاه موتوری یکپارچه ورقه‌کردن و خرد کردن غده کاساوا

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تاریخ پذیرش: ۱۴۰۴/۱۱/۱۳

## چکیده

مطالعه‌ای برای بررسی دستگاه موتوری یکپارچه برش دادن و خرد کردن غده کاساوا (مانیوک) انجام شد. این دستگاه یکپارچه از نظر معیارهای کلیدی عملکرد در سه سطح سرعت (۹۵۰، ۱۱۵۰ و ۱۳۵۰ دور در دقیقه برای خرد کردن؛ ۳۰۰، ۴۵۰ و ۶۰۰ دور در دقیقه برای برش) و دو سطح نرخ تغذیه (۱۰ و ۱۵ کیلوگرم در دقیقه برای خرد کردن؛ ۵ و ۱۰ کیلوگرم در دقیقه برای برش) مورد بررسی قرار گرفت. طبق یافته‌های تحقیق، حداکثر ظرفیت خرد کردن ۲۲۹/۷ کیلوگرم در ساعت در سرعت دورانی ۱۳۵۰ دور در دقیقه و نرخ تغذیه ۱۰ کیلوگرم در دقیقه ثبت شد. حداکثر راندمان خرد کردن ۸۲/۱ ٪ در سرعت دورانی ۱۳۵۰ دور در دقیقه و نرخ تغذیه ۱۵ کیلوگرم در دقیقه به‌دست آمد، در حالی‌که حداقل تلفات مکانیکی ۹/۰۶ ٪ در سرعت دورانی ۱۳۵۰ دور در دقیقه و نرخ تغذیه ۱۵ کیلوگرم در دقیقه مشاهده شد. بر اساس نتایج تحقیق، در سرعت دورانی ۶۰۰ دور در دقیقه و نرخ تغذیه ۵ کیلوگرم در دقیقه، بیشترین ظرفیت برش‌دهنده ۱۱۴/۸ کیلوگرم در ساعت مشاهده شد. در سرعت دورانی ۶۰۰ دور در دقیقه و نرخ تغذیه ۱۰ کیلوگرم در دقیقه، بیشترین راندمان برش‌دهنده ۷۱/۶ ٪ به‌دست آمد. در این سرعت و نرخ تغذیه، کمترین تلفات ۱۱/۰۶ ٪ نیز مشاهده شد. به دلیل پایین بودن معیارهای کلیدی عملکرد ثبت‌شده در طول تحقیق، بهینه‌سازی درام و قیف واحد خردکن و همچنین هندسه قیف و تیغه واحد برش پیشنهاد می‌شوند.

**واژه‌های کلیدی:** تلفات مکانیکی، راندمان، سرعت عملیاتی، ظرفیت، نرخ تغذیه

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