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Development and Performance Evaluation of Cassava Slicing Machine

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Abstract— *The lack of postharvest technology has been a major factor contributing to the low production of cassava in Ethiopia. However, efforts are being made to address this issue by developing a cassava slicer to enhance cassava production and productivity. The development of a cassava-slicing machine using corrosion-resistant material has proven to be effective and efficient. Cassava roots degrade within 48 hours after harvest, making it necessary to process them into a dried product to prolong shelf life. Hand slicing is the cheapest method but is labor-intensive, time-consuming, and dangerous. Therefore, the development and performance evaluation of an electrically powered cassava slicing machine became necessary. The objective of the study was to transfer power from a 2.5 hp single-phase electrical motor to a circular slicer disc using a shaft mounted on a frame made of milled steel. The performance of the prototype was evaluated based on parameters such as machine capacity, slicing efficiency, and slicing damage. The developed cassava slicing machine demonstrated a slicing capacity of 982.45 kgh^{-1}., slicing efficiency of 87%, and damaged slices at 9.78% at a slicing disc speed of 500 rpm and feed rate of 11 kgmin^{-1}. The impact of speed on slicing capacity, efficiency, and damage was significant at $P < 0.05$ level according to ANOVA results. Overall, the development of this cassava-slicing machine is a significant step towards improving cassava production in Ethiopia by addressing postharvest challenges effectively and efficiently.*

Keywords— *Capacity, Cassava root, Damaged, Efficiency, Performance evaluation.*

I. INTRODUCTION

Cassava (*Manihot esculenta Krantz*) is an important stable crop recognized as a 21st century crop mostly for smallholder farmers [1]. According to the Food and Agriculture Organization of the United Nations, it is one of over 100 species of trees, shrubs, and plants of the genus Manihot that are believed to have been introduced to the United States from northern Argentina. One of the most important tuber crops in many developing tropical economies today is cassava (Manihot esculenta Krantz). Additionally, the Portuguese brought it to Africa for the first time in the Congo Basin in about 1558 [2]. Cassava requires more labor than other staple crops; however; it requires considerable post-harvest labor because the roots are highly perishable and must be processed into a storable form immediately after harvest [3]. In 2018, approximately 278 million tons of cassava root were produced worldwide, with Nigeria accounting for 21% of this total. Thailand, the Democratic Republic of the Congo, Brazil, and Indonesia were also major cassava producers [3].

In Ethiopia, cassava is a significant staple crop. Especially in rural areas, it provides food and income for a large number of people. Cassava is a crop with multiple uses since it can be processed into a variety of products, including flour, chips, and starch. Small-scale subsistence farmers in resource-constrained areas cultivate it throughout the country's south, southwest, east, and northwest [5].

Cassava is a crop that grows widely in Ethiopia, primarily in the southern region. In order to offer food security for subsistence farmers whose crops have failed due to drought, NGOs and other groups have introduced cassava to parts of Ethiopia that are prone to drought. Because cassava is a resilient crop that can tolerate severe weather, it may be able to support the lives of farmers in these regions. Farmers in these regions typically cultivate cassava in tiny, erratic, dispersed plots, either alone or in combination with other legumes like enset, maize, and sweet potatoes [6]. In 2013, the average total coverage and cassava production annually in Ethiopia's Southern region was 195,055 hectares with a yield of 501,278.5 tons [7]. Cassavas have a significant role in generating income, protecting resources, ensuring year-round access to sustainable food, and ensuring food security [8]. It is also a potential food crop in Ethiopia and has been appreciated since the 1984 famine [9]. The ability of cassava root to develop entirely well in lousy soil and its innate capacity to stay for a long time in the ground even after maturity are both essential qualities that have made it an important food security crop, especially among low-income countries [10], Which can be stored for more than three years in the ground before being used.

The most significant root crop and a cheap energy source in tropical areas was cassava, which has a higher calorific value than most starchy crops [11]. Fresh cassava roots have a starch content of roughly 30% and provide the largest production of starch per area of any known crop [12]. The protein content is extremely low. which ranges from 1 to 3% (13]. After harvesting, cassava roots are processed by various methods into different products; the various unit operations involved include peeling, slicing, grating, fermenting, drying, and other final processes.

Out of the above-listed cassava processing unit operations, peeling and slicing were challenging tasks to carry out manually due to the irregularity of the shape of the cassava tuber. Cassava can be consumed fresh or in various industrially or traditionally processed forms, depending on personal preference and local

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customs. One of these items is cassava flour. It is still a staple food in many parts of the world because it is less expensive than wheat or other grains [14]. In southern parts, processing cassava is used chiefly for size reduction by females and young people. The average capacity of manual slicing in two younger females was 30kg/hr. It is very time-consuming and inefficient. It also results in inconsistent slice thickness sizes since it is challenging to control slice sizes, which affects drying time. Due to ineffective and efficient drying brought on by uneven and asymmetrical lengths, the drying uniformity is affected, and the quality of the dried slice is not suitable for the requirements demanded by consumers. A well-designed slicer is necessary for the slice to dry evenly and quickly to achieve symmetry.

Therefore, slicing can improve cassava products quality, even though the process is not extensively used in cassava processing. Reduction in the size of the cassava roots to be processed into a food product that requires fermentation and drying has been an effective means of reducing the processing time and improving the quality of the product. This research work aimed to fill the technological gap by designing and developing for power-operated cassava slicing Machin.

II. MATERIAL AND METHODS

Material

In terms of design and manufacture, material selection was an essential step. One of the most important factors to consider when selecting the appropriate material for food processing is corrosion. [15]. The right material selection helped to lower development costs in addition to preventing corrosion issues. Stainless steel, sometimes referred to as corrosion-resistant steel, is a type of steel that rusts, corrodes, or discolors more slowly than regular steel. The machine's development took into account the machine's theory, mechanism, and material strength.

The materials selected for the constructions were based on ease of fabrication, toughness, machinability, availability, corrosion resistance and cost. During the construction of parts of the machine that have direct contact with the cassava sliced product or tubers like a slice disc, and slicer blade a great concern was given to food contamination. So, the slicer disc and blade were constructed with a stainless-steel material. Whereas other parts like Aluminum sheet metal for hopper and protective cover but the frame was constructed in angle iron milled steel by considering the durability of the developed machine to meet the expected working lifetime.

Methods

For effective operation, the electric motor-operated cassava root slicer will consist of basically the following components: slicing blade, slicing disc, mainframe, power unit, shaft, pulley, ball bearing, disc cover, belt feeding chute, and output chute. The choice of the component parts used in constructing the cassava slicing equipment was founded on strength, durability characteristics and economic considerations.
Therefore, the machine design considerations are as follows:

I. Compactness and simplicity of use.
II. The slicing components should be corrosion-resistant to avoid contamination of the crops being sliced.
III. The machine would be cost effective and easy to operate.
IV. The magnitude of requisite force for slicing of cassava roots.

The diameter of slice disc (405) mm, length of slicing blade and thickness (150 and 2 mm), shaft diameter (30 mm), pulley size (D2, 325 mm), belt wrap (12.7°), and angle of contact (154.2°), center distance (532 mm), tension of the belt (189.38 and 371.19 N), power transmission (1.98 K watt) torque (64 Nm) were determined from the generic equation presented in [16]. The load arrangement of the slicing machine is shown in Figure 1. The free-body diagram shown in Figure 1 is the representation of the vertical forces acting on the shaft. To obtain the reactions at each bearing, a moment is taken about the two expected bearing points independently. The total reaction on the bearing is given as follows.

$\sum MRC = 0$ assume clockwise direction as positive

395 N × 0.805 m – RD (0.805 m + 0.285 m) -332 N × (0.01) = $RD = \frac{314.58\ N}{1.09}$, RD $= 288.6$ N

$\sum FY = 0, -332\ N + RC - 395\ N + 288.6\ N =$ RC $= 438.4$ N

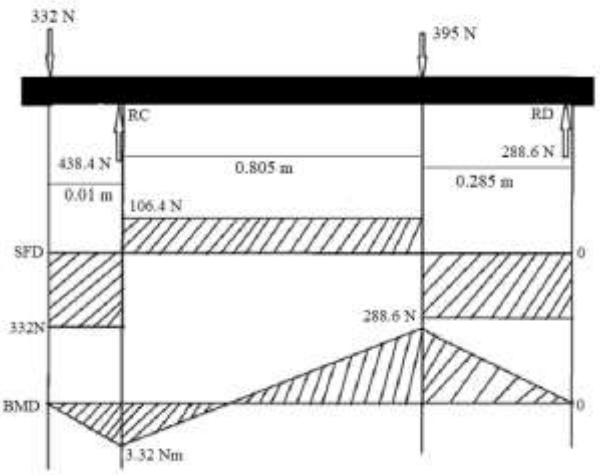

Fig. 1. Load calculation

Description and Principle of Operation of a Cassava Slicing Machine

Figure 2 shows a picture of the cassava-slicing machine. The slicer was powered by an electric motor, which was transferred to the input shaft via a pulley system from the motor. Roots were manually fed into the hopper one at a time. The entire roots drop on the slicer through the hopper and then cut as the operator manually feeds it against the rotating blades. The input shaft powers the cutting mechanisms, which consist of a slicer disc with a connected slicer blade. The thickness of each slice was determined by the sliced cassava dumped space between the rotating slicer disc and the slicer blade. When the Slicer disc rotates through the shaft, the tube is sliced by the slicer blade and the sliced discharge is out throughout by gravity. The Slicing has selected an appropriate slicer disc blade based on its thickness clearance adjustment. The designed machine requires one operator at a time due to its simplicity in design.

Fig. 2. Developed cassava slicer machine

Experimental procedure

One freshly harvested Cassava variety (Kello 44/72) was purchased from a farmer's farmland in the Wolayta zone, South Nation nationality people of Ethiopia. The harvesting age was 18 months and all the physical and mechanical properties of this variety were determined. The roots were first peeled and washed to remove some contact contamination and dust. A digital weighing scale (YP 2001N Electronic Balance) was used to determine the weight of the samples in each experiment. An electromagnetic adjustable speed motor (YCT 132-4B) was used for adjusting the slicing disc speed (200,300,400, and 500 rpm) in each experimental unit, which controls the speed between 125–2500 rpm. The average moisture content of the sample was determined as 62.92 % in a wet base measured in a dry oven for 24 hr. at 105^0c similar to that carried out by [17].

Preliminary tests were conducted to determine the optimum feed rate, speed of the machine, and its arrangement correctness. For each experiment cassava root was weighed and manually hand-fed into the slicing hopper. The output material obtained from the machine outlet was collected and separated into two groups, that is, undamaged slice material and damaged slice material. The mass of each category was determined by and electronic balance.

The machine was assembled correctly and aligned with the cassava-slicing device. Before it was evaluated, the machine's rotating parts were lubricated to reduce friction. The belt was connected to the pully and the electric motor. The electric power was supplied to the machine via an electric motor and test run at four different speeds (200,300,400,500) rpm and three different feed rates (5, 8, and 11) kgmin^{-1} into the machine to study the machine's behavior. It was seen during this process that the blade rotated without trembling. A two-way ANOVA was conducted to examine the effects of disc speed and feed rate separately for the response variable capacity, slicing efficiency and damage.

Performance Criteria

The data obtained were subjected to Analysis of variance using R- statistical software. A test of significance was also conducted at 5% probability level. The testing parameter of the machine such as capacity, efficiency, and weight of slicing damage was computed using the following Equation 1 – 2 ([17]; [18] respectively.

$$\text{Machine Capacity (Mc)} = \frac{Wn}{T} \qquad (1)$$

$$\text{Slicing Efficiency } (\eta) = \frac{Wn-Wd}{Wn} \qquad (2)$$

Where: η = Slicing efficiency, (Mc) = Machine Capacity Wn = weight of normal sliced, T = Time taken to slice (hr.), Wd = weight of damaged sliced material (when dry, it is easily carried away by the wind).

Statistical analysis

The collected data were analyzed using the R statistical software version of R4.2.1. The analysis of the data shows whether there was a relationship between independent and dependent variables. Confidence intervals of 95% were used to show the significance of the relationship between variables; 'p < 0.05' showed that the relationship was significant.

III. RESULT AND DISCUSSION

Performance evaluation

The ANOVA results for machine capacity, slicing efficiency and weight of damage are presented in Table 1, Table 2 and Table 3 respectively. There were statistically significant main effects of disc speed '$p < 0.0001$' and feed rate '$p < 0.05$' on machine capacity. The interaction of disc speed and feed rate had significant effect on machine capacity at 5% probability level. Our findings is in agreement with [19], which reported that machine speed has significant '$P<0.05$' effect on both throughput capacity and machine capacity of the cassava slicing chips. [20] also found that an increase in the chipping capacity with a corresponding increase in the operational speed.

TABLE1. Analysis of variance for machine capacity

	Sum Sq	Df	F value	Pr(>F)	
Speed	210923	3	31.7377	1.61E-08	***
Feed rate	15492	2	3.4967	0.046483	*
Speed*Feed rate	52595	6	3.957	0.006839	**
Residuals	53167	24			

TABLE 2. Analysis of variance for slicing efficiency

	Sum Sq	Df		F value	Pr(>F)	
Speed	101.091	3		6.5759	0.00211	**
Feed rate	47.791	2		4.6632	0.01946	*
Speed*Feed rate	3.581	6		0.1165	0.99348	
Residuals	122.983	24				

TABLE 3. Analysis of variance for weight of damage

	Df	Sum Sq	F value	Pr(>F)	
Speed	3	0.59908	8.4476	0.000524	***
Feed rate	2	0.81965	17.3369	2.19E-05	***
Speed*Feed rate	6	0.03124	0.2203	0.966442	
Residuals	24	0.56733			

Regression Analysis

Model performance is strongly affected by the input variables., therefore, determining which variables are most useful for prediction is critical. It is critical to choose the proper variables since incorrect input variables result in redundancy and reduced model interpretability. In this study Pearson correlation coefficient was used to measure the correlation between various variables and dependent variables (machine

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capacity, efficiency, and weight of damage). Figure 3 showed the results of the correlation analysis. The Pearson coefficient values were always between 1 and -1. Positive R-values are indicated in blue color, while negative R-values are indicated in red color.

Fig. 3. Pearson correlation matrix

Once the Pearson correlation is done, multiple linear regression model was fitted to the experimental data and statistical significance of linear and interaction effects were analyzed for machine capacity, slicing efficiency and weight of damage responses variables separately. Stepwise regression was used to find the best subset of the regression model that is appropriate for the dataset. The regression summery for response variable machine capacity, slicing efficiency and weight of damage is presented in Table 4, Table 5 and Table 6 respectively. It revealed that the models were highly significant at 1 % level of significance.

TABLE 4: Summary of regression for machine capacity

	Est.	S.E.	t val.	p
(Intercept)	229.8	96.34	2.39	0.02
Feed rate	39.05	11.52	3.39	0
Speed	1.6	0.26	6.1	0
Feed rate*Speed	-0.09	0.03	-2.98	0.01

TABLE 5: Summary of regression for slicing efficiency.

	Est.	S.E.	t val.	P
(Intercept)	93.67	1.61	58.07	0
Speed	-0.01	0.003	-4.79	0
Feed rate	0.38	0.14	2.67	0.0116

TABLE 6: Summary of regression for weight of damage

	Est.	S.E.	t val.	P
(Intercept)	-0.22	0.11	-2.01	0.05
Feed rate	0.06	0.01	6.2	0
Speed	0.001	0.0002	5.44	0

The regression equation describing the effects of input parameters on machine capacity, weight of damage and slicing efficiency are given in equations 3.1, 3.2 and 3.3 respectively.

$$Capacity = 229.8 + 39.1 * FR + 1.6 * S - 0.09 * (FR * S) \quad (3.1)$$

$$Perecent\ damage = -0.22 + 0.06 * FR + 0.001S \quad (3.2)$$

$$Sclicing\ efficiency = 93.7 - 0.015 * S - 0.38 * F \quad (3.3)$$

Where: FR = feed rate and S = speed

Effect of Speed on the Throughput Capacity

The result revealed that an increase in the speed of the machine resulted in a decrease in slicing time and an increase in machine capacity. With higher speeds, the machine could cut more produce in less time. This is in agreement with the findings of [21] and [20], throughput capacity increased when operational speed increased. Figure 4 presents the effect of motor speed on machine capacity at greater capacity achieved at speeds of 400 and 500 rpm than at 300 and 200 rpm. The average throughput capacity of the slicer was found to be 840.212 kg h^{-1} at a speed ranging from 200 to 500 rpm and a feed rate ranging from 5 to 11kg/min. [20], reported a slicing capacity of 346 kgh^{-1} and a slicing efficiency of 87.09% for a test run of the chipper/slicer. The variations in throughput capacity and efficiency among the different authors might be due to the different varieties of the sample utilized, the chipper/slicer design specification, the number of blades, the time spent processing the produce after harvest, the age of the tubers, as well as operator inefficiency. In comparison to the published throughput capacity and machine efficiency in the literature, the newly developed cassava slicer machine was greater throughput capacity due to the number of cutting blades and its slicing blade thickness adjustability.

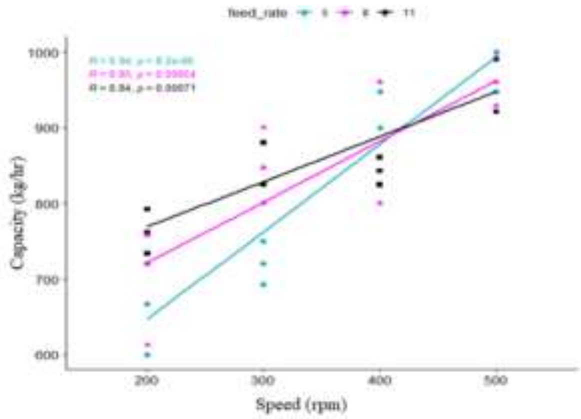

Fig. 4. Effect of motor speed on throughput capacity of machine

The effect of speed on Slicing Efficiency

Figure 5 presents the effect of machine speed on slicing efficiency at different feed rates. As the speed of the machine increases, slicing efficiency reduces. From the figure, as the speed increases from 200 to 500 rpm, slicing efficiency reduced from 93.5 to 91 % for 5 $kgmin^{-1}$ feed rate, from 94.2 to 91% for 8 $kgmin^{-1}$ feed rate and from 92 to 87% for 11 $kgmin^{-1}$ feed rate. Therefore, as the speed increases, the force of chipping increases. However, due to the higher force, there was the tendency of an increase in the speed of the slice as it is chipped off from the cassava which might result in damaging the slices as they strike the inner walls of the slicing chamber. This might be the result of decreased efficiency obtained at 500 rpm as less mass of properly sliced cassava will appear, thus decreasing the efficiency.

Effect of motor speed on the weight of damage

The effect of motor speed on the weight of the damage is presented in Figure 6. It was observed that mechanically damage increases as the motor speed increases. The highest damage (9.78%) was recorded for a combination of 500 rpm motor speed, while the minimum (5.57 %) was recorded for 200 rpm motor speed and 11 kgmin^{-1} feed rate. When we compared the slice damaged between feed rates, 11 kgmin^{-1} had the highest damaged slice than 8 and 5 kgmin^{-1} feed rate. This is because when the feed rate increases, so does the operational duration, result in an increase in the number of impacts between the cutting blade and the tubers, which increases the damage.

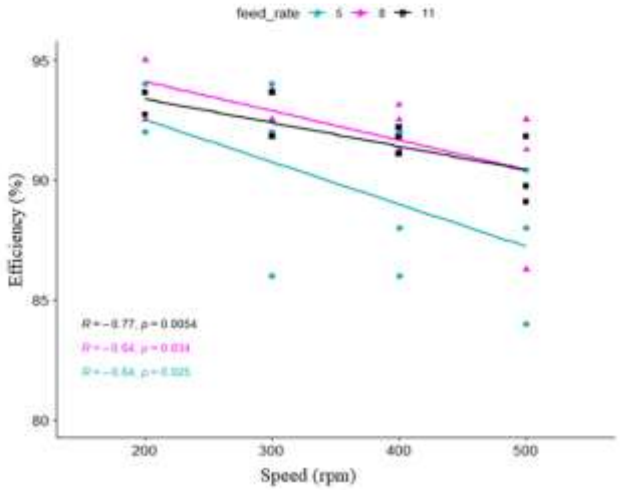

Fig. 5. Effect of motor speed on the machine slicing Efficiency

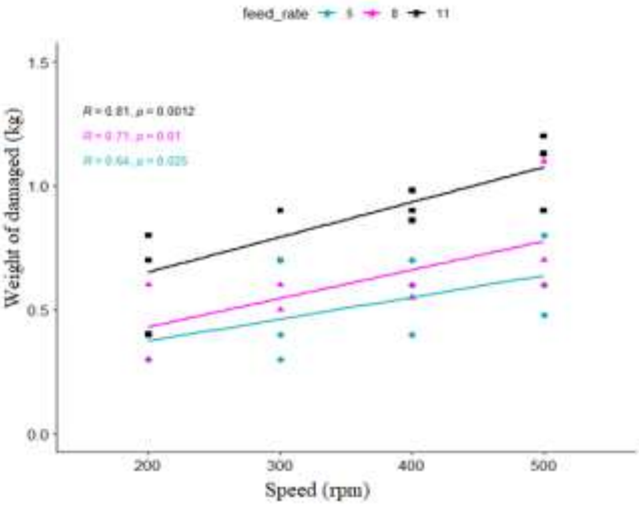

Fig. 6. Effect of motor speed on slicing damage

IV. Conclusion and Recommendation

Conclusion

The developed cassava slicer machine was tested and evaluated to determine the effect of slicing disc speed and feed rate on slicing efficiency, throughput capacity, and the weight of damaged slicing produced by the slicing machine. The test was performed at slicing disc speeds of 200, 300, 400, and 500 rpm and feed rates of 5, 8, and 11 kgmin^{-1}. The independent variables were motor speed and feed rate, and the dependent variables were throughput capacity, slicing efficiency, and slicing damage weight. The experimental design was a factorial RCBD with four levels of operational speed and three levels of feed rates 4 × 3, each with three replicates, for a total of 36 experimental units. The maximum slicing throughput capacity (982.45 kgh^{-1}) was recorded at 500 rpm slicer disc speed, 5 kg/min feed rate. It was also observed that the highest damage (9.78%) was recorded for a 500-rpm motor speed, while the minimum (5.57) was recorded for a 200-rpm motor speed and 11 kgmin^{-1} feed rate. The effect of motor speed on slicing efficiency shows, that as the speed increases from 200 to 500 rpm, slicing efficiency reduced from 93.5 to 91 % for a 5 kgmin^{-1} feed rate, from 94.2 to 91% for 8 kgmin^{-1} feed rate, and from 92 to 87% for 11 kgmin^{-1} feed rate.

Their results demonstrated that there was a strong linear direct relationship between slicing disc speed and the throughput capacity and as a consequence, one needs to take due consideration to the disc speed during slicing to get the optimum capacity. The amount of speed in the slicer disc increases the throughput capacity of the machine also increases, however, the relationship between slicer disc speed in the slicing efficiency and slice damage weight is not directly proportional or interrelated. Therefore, the choice of slicing capacity and the slicing efficiency is dependent on the operational speed of the motor. This thesis work is primarily focused on the development and performance evaluation of a cassava slicing machine, with operational speed and feed rate serving as test and evaluation parameters. Cassava tuber parameters such as harvesting age, moisture content and size interaction with motor speed and slicing clearances should be studied further in the future.

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