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Performance Evaluation of Electric Motor Driven Turmeric Slicing Machine

Amanuel Erchafo ERTEBO[a*]

[a]*Department of Agricultural Engineering Research Process, Melkassa Agricultural Research Center, P.O.Box 436, Adama, ETHIOPIA*

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

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ABSTRACT

This study investigated the performance of an electric motor driven turmeric rhizome slicer machine. The physical properties of turmeric rhizome such as geometric mean diameter, arithmetic mean diameter, square mean diameter, equivalent diameter, aspect ratio, sphericity, shape factor, bulk density, porosity, coefficient of friction, and angle of repose were studied. According to the determination results, these parameters were found to be 23.9 mm, 30.3 mm, 45.3 mm, 33.2 mm, 0.33, 0.4, 1.8, 336 kg m^{-3}, 81.7%, and 28.4°, respectively. It was observed during the test that the machine slices the rhizomes of turmeric into slices with a desired thickness range of 1.5 to 2 mm. According to findings, at 500 rpm rotor speed and 10 kg min^{-1} feeding rates, the maximum slicing capacity of 824.7 kg h^{-1} was recorded; at 300 rpm rotor speed and 15 kg min^{-1} feeding rates, the minimum slicing capacity was recorded. At 500 rpm of rotor speed and 15 kg min^{-1} of feeding rate, a maximum slicing efficiency of 97.4% was found, while at 300 rpm and 10 kg min^{-1} feeding rate, a minimum slicing efficiency of 93.9% was noted. From test results, at 500 rpm rotor speed and feed rates of 15 kg min^{-1}, the minimum material loss was recorded as 4.06%, while at 300 rpm rotor speed and 10 kg min^{-1} feed rate, the maximum material loss was recorded as 7.6%. This turmeric slicing machine is highly recommendable because the machine's performance for slicing the rhizome of turmeric was very impressive based on the test results.

Keywords: *Turmeric slicer, Slicing capacity, Slicing efficiency, Material loss, Rotor speeds*

INTRODUCTION

Turmeric (*Curcuma longa* L.) is a spice crop produced in tropical and subtropical regions which is typically utilized for both culinary and medicinal targets. Turmeric is a perennial herbaceous crop belonging to the tuberous rhizomes with members of gingers (Shi, 2020). It is a rich, golden-orange spice that enhances food's color, flavor, and nutritional value. Nearly one billion peoples' worldwide utilize turmeric as a spice (Polshettiwar *et al*., 2022). An estimated 1,100,000 tons of turmeric are produced worldwide each year (Nair, 2023).

Turmeric rhizome is a source of income for many Ethiopians which supports a large number of people in ways of life. As a key component of the regional sauce *Alicha Wot*, Ethiopian homemakers consider turmeric, or "Ird" in the Amharic language, one of the greatest flavorful spices. Turmeric is one spice that is produced primarily in Ethiopia by smallholder subsistence farmers in the country's southwest and southeast, regions (Hordofa and Tolossa, 2020). The output, production, and coverage of land of turmeric spices in Ethiopia were 3.95 tons per hectare, 3962.03 metric tons, and 1002.2 hectares, respectively (Deribe, 2021).

Turmeric rhizomes are harvested and then processed through some post-harvest steps, including slicing, boiling, drying, and polishing to create enduring commodities before being used (Girma and Mohammedsani, 2021).

Problems associated with turmeric slicing using conventional methods include their irregularity, which can lead to uneven drying or infected dry slices. In Ethiopia, the most time-consuming, tedious, and laborious method of processing turmeric is the conventional method of slicing it. This method has a limited output per time and requires a large number of workers to do the job. (Hailemariam *et al*., 2023). A major obstacle for producers of turmeric is the lack of mechanical turmeric processing technologies in the areas where turmeric is grown (Muogbo *et al*., 2017). Because of this, producers of turmeric reduced the size of the spice using hand instruments like hand knives and stationary curing units. However, this tool can cause harm to the operator's fingers and produce an uneven product that after processing has poor final quality due to variations in size, shape, or thickness. Due to a lack of turmeric processing technologies, Ethiopian farmers who grow turmeric often neglect to follow the crucial steps and avoid the most fundamental and crucial steps of curing, peeling, slicing, boiling, and polishing turmeric (Hailemichael *et al*., 2016).

Currently, turmeric is produced nationally by farmers, large private farms, massive investment projects, and small business owners, indicating a high demand for turmeric-slicing machines in Ethiopia (Hordofa and Tolossa, 2020). Turmeric crops have to be sliced using a slicing machine because of the increasing demand for processed turmeric for a variety of applications. As technology develops, it gets increasingly significant to slice turmeric using a slicer machine. The main purposes of slicing turmeric with a slicing machine are to achieve uniform drying, reduce the drying time, improve quality of products, and decrease the final moisture content in the small pieces of rhizomes without compromising the product's appearance.

Consequently, this study aimed to evaluate the performance of the motorized fresh turmeric rhizome slicing machine in order to minimize the technological gap in turmeric slicing in turmeric growing areas of Ethiopia, avail the turmeric slicer machine for future intervention, and generate information regarding the slicer machine's effectiveness for beneficiaries. The study also aimed to replace the conventional slicing of turmeric with a machine, which would slice the spice more quickly and with higher quality while reducing labour intensive tasks.

MATERIALS and METHODS

Study area

Evaluating the performance of the turmeric slicing machine was carried out in southwestern parts of Ethiopia, Tepi National Spices Research Center is situated 579 km from Ethiopia's capital, A.A. The site is located with a latitude of 7º3' N and a longitude of 35º0' E with an altitude of 1200 m above sea level.

Description of slicer machine

The turmeric rhizome slicing machine was powered by a three-horsepower (3 hp) variable electric motor which rotates at a constant rotor speed of 1500 rpm. The machine mainly consists of a feeding table, hopper, cylindrical disc, cutting blade, blade holder, outlet, frame, shaft, and power transmission units. The slicing unit was made up of a cylindrical stainless steel sheet metal. Its slicing mechanism could be based on a cutting blade when the actual slicing operation takes place on it. Turmeric slicing machine is easy to use, less complicated to operate and it has only one or two people to control the whole process. Due to its simple operating mechanism, this turmeric slicing machine was an excellent choice for farmers who produce turmeric. The machine was capable of slicing at a uniform dimension, was fast enough, lasted longer in use with high efficiency, and was portable and affordable for small-scale farmers, businessmen and individuals.

Materials

Experimental materials

The sample of turmeric (Figure 1) was obtained from the southwestern parts of Ethiopia, Tepi National Spices Research Center or Tepi Agricultural Research Center experimental field for calculating properties as well as detailed tests on the turmeric slicing machine. The materials used in the experiment were turmeric rhizomes of the Tepi-1 (Bonga 51/71) variety. This variety should be selected because of its availability and its well-known for its high production capacity in the Tepi area and other growing areas of southern Ethiopia.

Figure 1. *Turmeric rhizome for experiment.*

Measuring instruments

The multiple measurements on the fresh turmeric rhizome have been implemented. The lengths of the turmeric rhizomes were determined with the aid of a pocket meter, this measuring pocket meter can measure a minimum length up to 0.5 cm, therefore, its sensitivity is 0.5 cm. The turmeric rhizomes' diameter was taken by the caliper with its 0.01 mm accuracy; the sensitivity of the caliper is 0.02 mm which means that the smallest measurement that can be read using this instrument is 0.02 mm. A mass of turmeric rhizomes was taken by using weight balances. The sensitivity of a digital weighing balance is 1 mg with a model of YP150001; 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. The stopwatch was utilized for recording slicing time when testing a slicer. The machine's rotor speed was measured using a contact type of tachometer. The machine was started, and the speed was adjusted to 300 rpm, 400 rpm, and 500 rpm by using a tachometer.

Methods

Determination of physical properties of turmeric rhizomes

Determining different properties for agricultural produce is essential for designing agricultural machinery and the improvement of processes for harvesting, handling, postharvest operations, and storage (Obaia and Ibrahim, 2015). The properties of fresh turmeric rhizomes are useful for the design of turmeric processing equipment, handling and storage. Determining the characteristics of those products is important to designing machines and processes conveying, for designing feed hoppers and metering mechanisms. Food products like turmeric are often characterized based on their physical dimension (length, width, thickness) and density since these properties are utilized for processing (Ramos *et al.*, 2021).

While determining the physical characteristics like thickness, lengths, breadth, arithmetic diameters, geometric diameters, square diameters, equivalent mean diameter, sphericity, aspect ratio, unit volume, surface area, shape factor, bulk and true density, porosity, angle of repose, and moisture contents for turmeric rhizome random choices were carried out 100, 80, 50, 33, 36, 34, 30, 35, 27, 38, 40, 25, 100, 60, 35, 46, and 54 respectively. As a consequence, the following physical characteristics have been investigated:

Turmeric rhizome's axial dimensions

Fresh turmeric rhizomes were randomly selected for measuring the axial dimensions such as lengths, breadth as well as thickness.

Geometric mean diameter

A diameter was an important measurement criterion and was expressed as the cub root of three axes of the mother rhizome using the major length (l), breadth (b) and diameter (d). It's the mean value for turmeric mother rhizome is ascertained by applying Equation 1 (Dhineshkumar and Anandakumar, 2016).

$$GMD = \sqrt[3]{l \times b \times d} \tag{1}$$

Where, *GMD* is the geometric means diameters, *l* is the major length (mm), *b* is the breadth (mm), and *d* is the diameter (mm).

Arithmetic mean diameter

The arithmetic mean diameter of turmeric mother rhizome samples was determined using the formula (Dhineshkumar and Anandakumar, 2016) in Equation 2.

$$AMD = \frac{(l+b+d)}{3} \tag{2}$$

Where, *AMD* is the arithmetic mean diameter (mm), *l* is the major length (mm), *b* is the breadth (mm), and *d* is the diameter (mm).

Square mean diameter

The square mean diameter of turmeric mother rhizome samples was determined using the formula (Dhineshkumar and Anandakumar, 2016) in Equation 3.

$$SMD = \sqrt[3]{lb + bd \times dl} \tag{3}$$

Where, *SMD* is the square mean diameter (mm), *l* is the major length (mm), *b* is the breadth (mm), and *d* is the diameter (mm).

Equivalent diameter

The equivalent mean diameter of turmeric mother rhizome samples was determined using the formula (Dhineshkumar and Anandakumar, 2016) in Equation 4.

$$EQD = \frac{(GMD+AMD+SMD)}{3} \tag{4}$$

Where, *EQD* is the equivalent mean diameter (mm), *GMD* is the geometric mean diameter, *AMD* is the arithmetic mean diameter (mm), and *SMD* is the square mean diameter (mm).

Sphericity

Sphericity of turmeric mother rhizome samples was determined using the formula by (Ramos *et al.*, 2021) given in Equation 5.

$$\Phi = \frac{\sqrt[3]{lbd}}{l} \tag{5}$$

Where, *Φ* is the sphericity (mm) *l* is the major length (mm), *b* is the breadth (mm), and *d* is the diameter (mm).

Unit volume and surface area

The unit volume (V) and surface area (S) can be estimated by applying the Equations 6 and 7 (Ramos *et al.*, 2021).

$$S = \frac{(\pi B l^2)}{2l - B} \tag{6}$$

$$V=\frac{(\pi B^2 l^2)}{6(2l-B)} \quad (7)$$

Where, B is the cub root of breadth (mm) and l is the major length (mm).

Shape factor (ë)

It can be determined using Equation 8 (Ramos *et al.*, 2021).

$$\ddot{e}=\frac{(D)}{C} \quad (8)$$

Where, C is the unit volume per cubic breadth (mm) and D is the area per six times cubic breadth (mm).

Bulk density

The mass-to-volume proportion of the turmeric in a container was used to calculate bulk density. Rhizomes were filled in a measuring cylinder as well as mass of rhizomes was estimated. The bulk density of the rhizomes was estimated by applying Equation 9 (Rajkumar *et al.*, 2021).

$$\rho_B = \frac{Mass\ of\ rhizome}{Volume\ of\ rhizomes} \quad (9)$$

Where, ρ_B is the bulk density.

True density

The true density of fresh turmeric rhizomes was determined by the platform scale method. The known sample of fresh turmeric rhizome was taken and then immersed in a toluene. True density can be calculated using the following formula (Rajkumar *et al.*, 2021) given in Equation 10.

$$T_D = \frac{Mass\ of\ rhizome}{True\ Volume\ of\ rhizomes} \quad (10)$$

Where, T_D is the true density.

Porosity and aspect ratio

The mother rhizome of turmeric's porosity has been estimated by dividing its volume in voids by its percentages. It can be determined by the expression as reported by Ramos *et al.* (2021) as given in Equations 11 and 12.

$$n = \frac{T_D-\rho_B}{T_D} x100 \quad (11)$$

$$Ar = \frac{b}{l} x100 \quad (12)$$

Where, T_D is the true density, ρ_B is the bulk density, b is the breadth (mm) and l is the major length (mm).

Moisture content

The moisture content for turmeric rhizomes was determined using the standard oven drying method. The weighed samples were subjected to remove moisture at 105±2°C for 24 hours (AOAC, 2000). Moisture contents can be estimated utilizing Equation 13.

$$MC\ (wb)\% = \frac{W1 - W2}{W1} \times 100 \tag{13}$$

Where, W_1 is the initial mass (g), W_2 is the final mass (g) and MC is the moisture content of the turmeric rhizome.

Angle of repose

The angle of the repose was calculated by the formula given in Equation 14 (Rajkumar *et al.*, 2021).

$$Angle\ (\theta) = tan^{-1} \frac{H}{D/2} \tag{14}$$

Where, θ 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).

Coefficient of friction

Coefficients of friction for turmeric rhizome concerning various materials like aluminum, mild steel, as well as wood, were obtained through techniques stated by (Rajkumar *et al.*, 2021).

Test procedures

The samples of turmeric rhizomes were weighed, and each sample was fed to the machine through the hopper at a constant feed rate while the blade ran at various predetermined rotor speeds. The rhizomes were cleaned and washed manually to remove adhering soil, hairs and extraneous matter. The fed materials were pushed by the hand into the cutting disc against the stationary blade and were sliced into the desired thickness. The time taken to slice was recorded. The slicer was started, and the rotor speed was adjusted to 300, 400, and 500 rpm by using a speed regulator. The rotor speeds were chosen for testing the slicer performance on turmeric rhizome (Murumkar *et al.*, 2016a). To evaluate the performance of the slicer machine, a total of 225 kg of fresh turmeric rhizome free from deterioration, scuffs, scratches, and damage could have been used for the entirety of the experiment.

Evaluation of the slicing machine

The evaluation had been executed at a turmeric slicer at three chosen rotor speeds with a fixed cutting clearance (2 mm) after weighing the test sample of the turmeric rhizome. Evaluating the slicer machine (Figure 2) was conducted by considering the slicing capacity, slicing, efficiency, material loss, and slicing time. The test parameters such as slicing capacity, slicing, efficiency, material loss, and percentage of scattered turmeric rhizomes were investigated using the following formulas by Khurmi and Gupta (2005).

$$Slicing\ capacity\ (kg\ h^{-1}) = \frac{Ws}{T} \tag{15}$$

$$Slicing\ efficiency\ (\%) = \frac{Qo - Qb}{Qo} \times 100 \quad (16)$$

$$Material\ loss = \frac{Qi - Qo}{Qi} \times 100 \quad (17)$$

$$Percentage\ of\ scattered = \frac{Ws - Wsc}{Ws} \times 100 \quad (18)$$

Where, W_s is the weight of sliced turmeric in kilogram, T is the time taken to slice turmeric in hours, Q_o is the weight of turmeric collected in kilogram, Q_i is the weight of turmeric feed in kilogram, Q_b is the weight of a non-uniform slice in kilogram and W_{sc} is the weight of scattered.

Figure 2*. Slicer during testing.*

Cost estimation

The cost of operation for the slicing machine was estimated by calculating the material cost of the machine. Estimation of hourly operational costs of the slicer was based on the capital cost of the slicer, interest on capital, depreciation, cost of repairs and maintenance, electric costs, labor cost, tax and insurance. According to Lazarus (2008), the annual fixed and variable costs were calculated as follows:

$$D = \frac{C - S}{LXH} \quad (19)$$

$$I = \frac{CXS}{2} \times \frac{i}{H} \quad (20)$$

$$RM = 2.5\%\ x\ C \quad (21)$$

$$W = \frac{LW}{H} \quad (22)$$

Where, D is the depreciation (EB h^{-1}), C is the capital investments of slicer, S is the salvage values, L is the life of a machine in hours, I is the interest on capital (EB h^{-1}), i is the interest, RM is the repair and maintenance cost, W is the wages (EB h^{-1}), LW is the labor wage, and H is the working hours.

Statistical data analysis

The factorial design was employed in the experiment, and the three levels of rotor speed with two feeding rate levels were taken as treatments. The slicer rotor speeds were also taken into consideration as the main factor. There were eighteen experimental units in each of the three replicates of the experiments. Data analysis was done using Statistix 8 software and SPSS Statistics 23 software was used for generating graphs. The significant relationship in variables was indicated by using the ninety-five per cent confidence interval. The mean separation between treatment means was conducted by least significance difference (LSD) at a 5% level. Using a methodology suitable for the experiment's design, an analysis of variance was implemented in the data.

RESULTS AND DISCUSSION

Physical Properties of Turmeric Rhizome

Geometric properties of rhizome

The average of axial dimensions, geometric, gravimetric, and frictional properties of the Tepi-1 (Bonga. 51/71) variety of turmeric rhizome samples were determined, as given in (Table 1). Based on the results the turmeric rhizomes ranged in length from 17.4 to 112.8 mm, width from 10.6 to 25.6 mm, and thickness from 8.2 to 19 mm, in that order. It was determined that the length, width, and thickness had respective mean values of 59.8 mm, 17 mm, and 14 mm. The standard deviation was computed to be 22.8, 3.3, and 2.7. The results showed that the diameter of the geometric mean varied from 12.8 mm to 35.7 mm. 23.9 mm and 5.3 were determined as mean values as well as standard deviations, correspondingly. The arithmetic mean diameter varied from 13.1 to 51 mm. The mean values and standard deviations were determined to be 30.3 mm and 8.8.

The diameter of the square mean varied from 22.4 to 70.5 mm. After computation, mean values as well as standard deviations came out to be 45.3 mm and 10.9 mm. The equivalent mean diameter ranged from 16.1mm to 52.3 mm. Also, mean values as well as standard deviations were 33.2 mm and 8.3 mm, respectively.

Turmeric rhizome aspect ratios ranged from 0.28 to 0.4. The calculated mean value also has standard deviations obtained at 0.33 and 0.06, respectively. The rhizomes of turmeric had a sphericity ranging from 0.27 to 0.73, through mean as well as standard deviations of 0.4 and 0.1, correspondingly. The unit volume and surface area of turmeric rhizome were found in the range from $4.6x10^5$ to $5.5x10^8$ mm^3 and 436 to 390.2 mm^2. The average values of unit volume and surface area were estimated to be $8.5x10^7$ mm^3 and 1725.6 mm^2 with standard deviations of $1.2x10^8$ mm^3 and 809.6 mm^2, while mean also standard deviations for the shape factor of the turmeric rhizomes were found to be 1.8 and 0.2, respectively, ranging from 1.56 to 1.9. A similar trend was reported by (Thul *et al.*, 2022).

Gravimetric and frictional properties of turmeric rhizome

According to the findings (Table 1), the bulk density of the fresh turmeric rhizomes ranged from 294 to 378 kg m^3, while this density's mean and standard deviation were determined to be 356 kg m^3 and 42. The fresh turmeric rhizomes were found to have a true density between 1373 and 1381 kg m³ which had mean values of 1378 kg m³ and a standard deviation of 4.4. The porosity of the rhizome of turmeric ranged from 78% to 86.9%. The porosity was computed to have a mean of 81.7% and a standard deviation of 4.6. The fresh turmeric rhizomes had an angle of repose that varied from 26.6° to 31.2°, a mean of 28.4° and a standard deviation of 2.5. Results revealed that the fresh turmeric rhizome's mean moisture contents were obtained at 48% on a wet basis through standard deviations of 1.5. This moisture content ranged from 46.3% to 49.1%. The static coefficient of friction on sheet metal, wood, and rubber surfaces for turmeric rhizome was found in the average of 0.54, 0.78, and 0.84 with standard deviations of 0.11, 0.17, and 0.08, respectively.

***Table 1**. Physical characteristics of turmeric rhizome.*

Properties	Mean value	Standard deviation (SD)	Mean±SD	Maximum value	Minimum value	Coefficient of variation (CV)
Length (mm)	59.8	22.8	59.8±22.8	112.8	17.4	38.0
Width (mm)	17.0	3.3	17±3.3	25.6	10.6	19.7
Thickness (mm)	14.0	2.7	14±2.7	19.0	8.2	19.3
Geometric mean diameter (mm)	23.9	5.3	23.9±5.3	35.7	12.8	22.3
Arithmetic mean diameter (mm)	30.3	8.8	30.3±8.8	51.0	13.1	28.9
Square mean diameter (mm)	45.3	10.9	54.3 ±10.9	70.3	22.4	24.3
Equivalent diameter (mm)	33.2	8.3	33.2 ± 8.3	52.3	16.1	25.0
Aspect ratio	0.33	0.06	0.3± 0.06	0.4	0.28	18.9
Sphericity	0.4	0.1	0.43 ±0.1	0.73	0.27	24.4
Unit volume (mm^3)	8.5E+07	1.2E+08	$8.5e^7 \pm 1.2e^8$	5.5E+08	455635	40.29
Surface area (mm^2)	1725.6	809.6	1725.6 ±809.6	3903.2	436.0	46.9
Shape factor	1.8	0.2	1.8± 0.2	1.9	1.56	10.1
Bulk density (kg m^{-3})	336	42	336± 42	378	294	12.5
True density (kg m^{-3})	1378	4.4	1378 ± 4.4	1381	1373	0.3
Porosity (%)	81.7	4.6	81. ± 4.6	86.9	78	5.7
Angle of repose (°)	28.4	2.5	28.4±2.5	31.2	26.6	8.7
Moisture content (%)	48.0	1.5	48±1.5	49.1	46.3	3.2
Coefficient of friction (sheet metal)	0.54	0.11	0.54±0.11	0.64	0.4	20.8
Coefficient of friction (wood)	0.78	0.17	0.78±0.17	0.95	0.6	21.7
Coefficient of friction (rubber)	0.84	0.08	0.84±0.08	0.92	0.76	9.5

The findings demonstrated that when the moisture content of the fresh turmeric rhizome was increased, slicing performed more effectively. The test revealed that the rhizome's moisture content was the most crucial factor in maintaining the turmeric rhizome's ability to be sliced. Moisture content of the produce determines the shelf life and the keeping quality of the turmeric. Singh *et al.* (2018) have suggested that the drying of fresh turmeric to a safe limit of moisture content about 10% for milling and 6% for storage. The angle of repose is important in design and construction of the material handling system (Shirsat *et al.*, 2018). The obtained angle of repose showed that a slight inclination was required at the slicer feeding inlet for the rhizome to be fed simultaneously on the slicer machine. Studying the physical characteristics of the fresh turmeric rhizome was highly advantageous for primary processing machinery as well as post-harvest handling and testing equipment.

Also, from this study it was observed that the determination of engineering properties of fresh turmeric rhizomes is useful for design of turmeric processing equipment’s, handling and storage. The engineering property investigated in this study was the most important properties which mainly considered in the design of the machine components. It gives the proper guidelines to an engineer and designer for designing the machines that will be suitable for processing of agricultural materials (Shirsat *et al.*, 2018). The properties of turmeric rhizomes such as axial dimensions, geometric mean diameter, arithmetic mean diameter, sphericity, bulk density, true density, porosity, angle of repose, volume and surface area were studied. The same trend was stated by Thul *et al.* (2022). This study finding related with previous research findings conducted by Ramos *et al.* (2021). Similar findings were reported by Mishra and Kulkarni (2019) for physical properties of turmeric rhizome.

Evaluation of the slicer

The slicer's performance was assessed at three different rotor speed settings and two different feeding rate settings at mean moisture contents of 48% at the wet basis for fresh turmeric rhizome (Tepi-1 (Bonga 51/71)) concerning slicing capacity, slicing efficiency, material loss, slicing time, and percentage of scattered. After the machine had completed slicing turmeric, weight measurements were made for the whole sliced turmeric, the scattered turmeric rhizome, the weight uniform slice, the weight non-uniform slice, and the slicing time. During the test, it was noted that the machine slices the rhizomes of turmeric into slices with a desired thickness range of 1.5 to 2 mm. The machine's performance for slicing the rhizome of turmeric was very impressive based on the test results. Devarshi *et al.* (2023) noted a similar observation. The previous studies in the literature relating to slicing machines for turmeric crops were reported by Navyashree *et al.* (2024); and Adeleke *et al.* (2021). This finding was comparable with the findings stated by Katanga (2022).

Slicing capacity

Univariates analysis of variances for impacts in feed rates, rotor speeds, and their combination on the slicer machine's slicing capacity has been shown in Table 2. In accordance with the findings, analysis of variances revealed that impacts in rotor speeds, feed rates, and their interaction were significant at 5% due to the values for p being smaller than 0.05. The results suggested that feed rates, rotor speeds, and their interaction all had an impact on a machine's ability to slice. The observations for significance effects were in agreement with the findings of earlier researchers by

Adeleke *et al.* (2021). For root crop slicers, a similar trend was noted by Abubakar *et al.* (2019). The same funding pattern for a turmeric-slicing machine was reported by Agbetoye and Balogun (2009).

Table 2. *Univariate analysis of variance for slicing capacity.*

Sources	DF	SS	MS	F	P	
Replication	2	5.1	2.5			
Rotor speed	2	27374.6	13687.3	319.3	0.0000	*
Feeding rate	1	459.9	459.9	10.7	0.0084	*
S×F	2	588.6	294.3	6.87	0.0133	*
Error	10	428.7	42.9			
Total	17	28856.8				

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

The machine's mean slicing capacity varied from 714.9 kg h^{-1} to 824.7 kg h^{-1}, as can be seen in Figure 3. The slicing capacity increased from 714.9 kg h^{-1} to 824.7 kg h^{-1} as the rotor speeds increased from 300 rpm to 500 rpm. When rotor speeds increased, the slicer's capacity headed to increase, but feed rates caused it to decrease. According to this finding, the slicing capacity was inversely correlated with the feed rates of the turmeric rhizome and directly correlated with the rotor speeds.

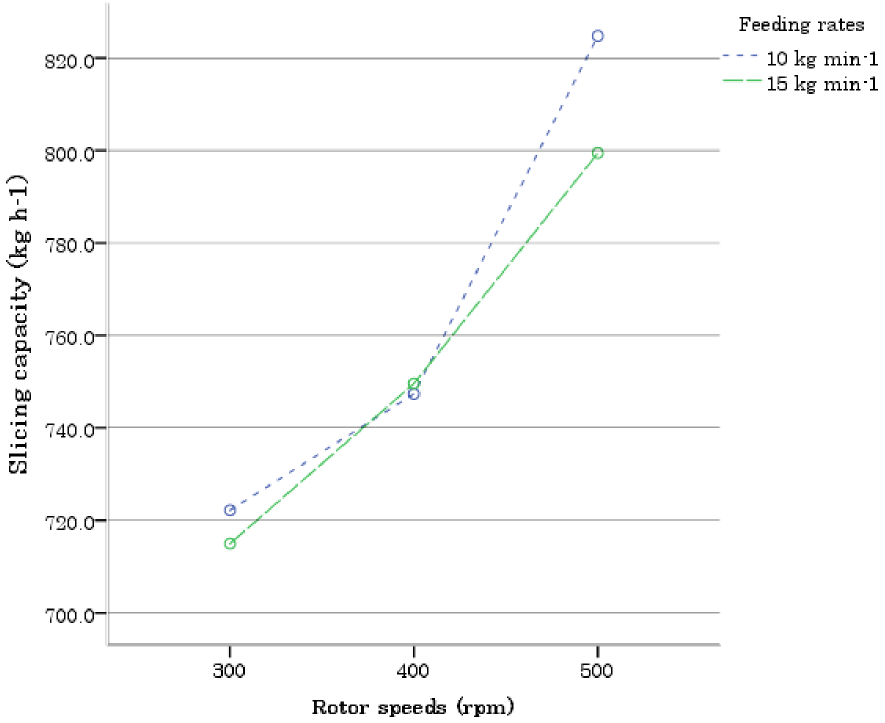

Figure 3. *Impact of rotor speed and feed rate on slicing capacity.*

According to findings, at 500 rpm rotor speed and 10 kg min^{-1} feeding rates, the maximum slicing capacity of 824.7 kg h^{-1} was recorded; at 300 rpm rotor speed and 15 kg min^{-1} feeding rates, the minimum slicing capacity was recorded.

The slicing capacity obtained in this study was higher compared to the value of 130.67 kg h^{-1} reported by Devarshi *et al.* (2023). Tanimola *et al.* (2019) stated the slicing capacity of 34.3 kg h^{-1} when slicing turmeric with a turmeric slicer. In comparison, Murumkar *et al.* (2016a) reported an average slicing capacity of 250 kg h^{-1} when testing the performance of a motor-operated slicer. Agbetoye and Balogun (2009) stated an output of 42.9 kg h^{-1} when testing an electric motor-powered slicer machine.

Slicing efficiency

Univariates analysis of variances for impacts in feed rates, rotor speeds, and their combination on the slicer machine's slicing efficiency has been shown in Table 3. The analysis of variances suggested that an impact of rotor speeds and feed rates were significant at 5% levels because of the values for p being lesser than 0.05 but their interaction impacts were non-significant (P>0.05). Depending on the result, the machine slicing efficiency was influenced by feed rates and rotor speeds excluding their relative interactions. The significant effects observations related with the previous researchers' findings by Adeleke *et al.* (2021). For root crop slicers, a similar trend was noted by Abubakar *et al.* (2019). The same funding pattern for a turmeric-slicing machine was reported by Agbetoye and Balogun (2009).

Table 3. *Univariate analysis of variance for slicing efficiency.*

Sources	DF	SS	MS	F	P	
Replication	2	0.0268	0.0134			
Rotor speed	2	31.7815	15.8908	19.34	0.0004	*
Feeding rate	1	4.3611	4.361	5.31	0.0440	*
S×F	2	3.8988	1.9494	2.37	0.1435	**
Error	10	8.2169	0.8217			
Total	17	48.2852				

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

In accordance with the test's result, it revealed that a slicer's mean slicing efficiency varied from 93.9% to 97.4%, as indicated in Figure 4. The slicing efficiency rose from 93.9% to 97.4% as rotor speeds increased from 300 rpm to 500 rpm. The machine's slicing efficiency looked after to rise as rotor speeds and feeding rates increased. This indicates a direct correlation between the rotor speeds and feeding rates of the experimental material and the slicing efficiency.

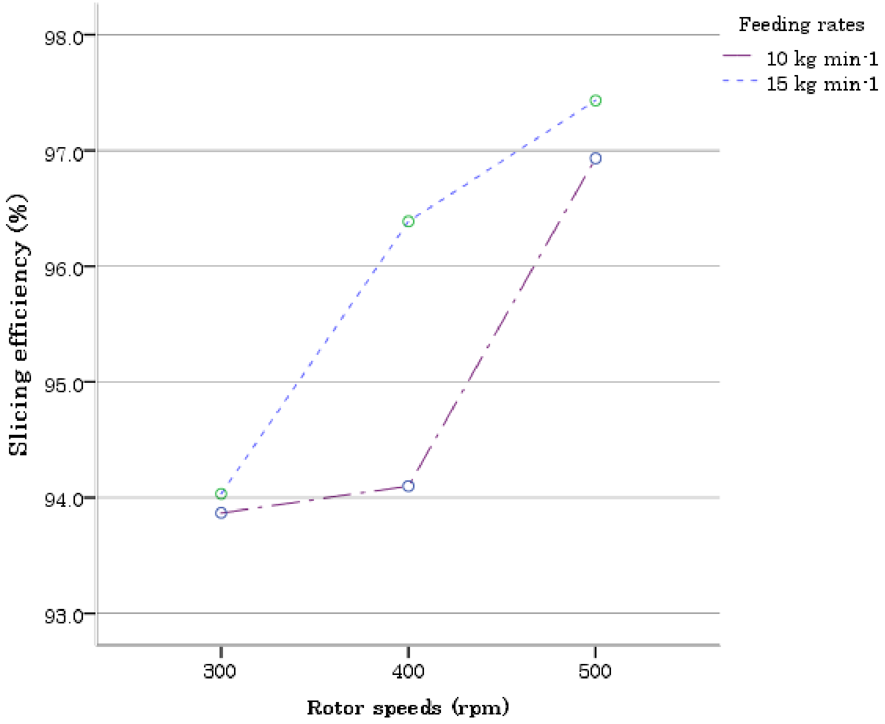

Figure 4*. Impact of rotor speed and feed rate on slicing efficiency.*

At 500 rpm of rotor speed and 15 kg min^{-1} of feeding rate, a maximum slicing efficiency of 97.4% was found, while at 300 rpm and 10 kg min^{-1} feeding rate, a minimum slicing efficiency of 93.9% was noted. The slicing efficiency obtained in this study was higher compared to the value of 94.07% reported by Devarshi *et al.* (2023). Tanimola *et al.* (2019) reported a machine efficiency of 59.8% while assessing turmeric slicer. In comparison, Murumkar *et al.* (2016b) reported an efficiency of 94.7% while assessing a motor-operated slicer. Agbetoye and Balogun (2009) reported a machine efficiency of 71% while assessing the slicer machine.

Material loss

Univariates analysis of variances for impacts in rotor speeds, feed rates, and their combination on the slicer machine's material loss has been shown in Table 4. In accordance with the findings, analysis of variances revealed that impact of rotor speeds and feed rates was significant at the five percent significance level due to the values for p being smaller than 0.05 but their interaction impact was non-significant which means the result obtained was greater than 0.05 ($P > 0.05$). The findings showed that, when their interactions were taken out of consideration, feed rates and rotor speeds had an impact on a machine's material loss. A comparable pattern for root crop slicers was observed by Abubakar *et al.* (2019). The same funding pattern for a turmeric-slicing machine is reported by Agbetoye and Balogun (2009). The significant effects observations related with the previous researchers' findings by Adeleke *et al.* (2021).

Table 4. *Univariate analysis of variance for material loss.*

Sources	DF	SS	MS	F	P	
Replication	2	0.0304	0.0152			
Rotor speed	2	31.6437	15.8219	19.3	0.0004	*
Feeding rate	1	4.4402	4.4402	5.42	0.0422	*
S×F	2	3.9184	1.9592	2.39	0.1417	**
Error	10	8.1947	0.8195			
Total	17	48.2274				

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

From the test result, a machine's mean material loss varied between 4.06% and 7.6%, as Figure 5 illustrates. The material loss dropped from 7.6% to 4.06% as the rotor speeds increased from 300 rpm to 500 rpm. As rotor speeds and feed rates increased, the machine's material loss looked after to decrease as well. This indicates that the rotor speeds and feed rates of the experimental material had a negative correlation with the material loss. A similar trend for slicers were stated by Murumkar *et al.* (2016a). The loss of the sliced rhizome occurred due to the lack of cover in front of the circular disc which caused the dropping of the slice far from the machine outlet.

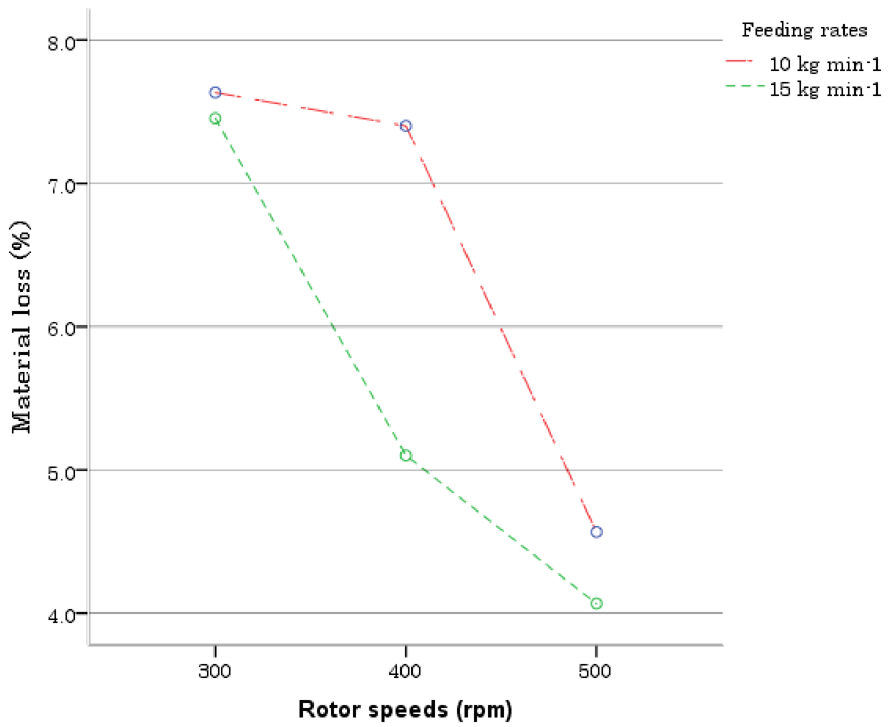

Figure 5. *Impact of rotor speed and feed rate on material loss.*

From test results, at 500 rpm rotor speed and feed rates of 15 kg min^{-1}, the minimum material loss was recorded as 4.06%, while at 300 rpm rotor speed and 10 kg min^{-1} feed rate, the maximum material loss was recorded as 7.6%. This rotor speed was given that, in comparison to the other rotor speeds, the 500 rpm rotor speed had a minimal loss. The minimum percentage of loss recorded in this study was lower than the 7.3% reported by Tanimola *et al.* (2019). In comparison, Murumkar *et al.* (2016b) reported a percentage loss of 4.58% when slicing turmeric with a turmeric slicer. Agbetoye and Balogun (2009) reported a loss of 8.7% while evaluating a slicer machine.

Slicing time

Univariate analysis of variance for impacts in rotor speeds, feed rates, and their combination on the slicer machine's slicing time has been shown in Table 5. Accordance with the analysis, an analysis of variances suggested that impacts in rotor speeds and feed rates were significant at 5% levels as a result of the values for p smaller than 0.05 however, their interaction impact was non-significant ($P > 0.05$). Based on the result, the machine slicing time was affected by feed rates and rotor speeds but was not affected by their impact interactions. A similar trend for root crop slicers was reported by Murumkar *et al.* (2016a). Comparable pattern for root crop slicers were observed by Abubakar *et al.* (2019). The same funding pattern for a turmeric-slicing machine was reported by Agbetoye and Balogun (2009).

Table 5. *Univariate analysis of variance for slicing time.*

Sources	DF	SS	MS	F	P	
Replication	2	0.4	0.2			
Rotor speed	2	1690.8	845.4	122.7	0.0000	*
Feeding rate	1	11250	11250	1633	0.0000	*
S×F	2	26.3	13.2	1.91	0.198	**
Error	10	68.9	6.9			
Total	17	13036.4				

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

It was noted that a machine's mean slicing time varied between 161 sec and 235 sec when fed at 10 kg min^{-1} with 500 rpm rotor speeds and at 15 kg min^{-1} with 300 rpm rotor speeds, as Figure 6 illustrates. In particular, the findings showed that the machine's slicing time had a tendency to decrease as rotor speeds increased and feed rates decreased. This is since higher rotor speeds performed more rapidly than smaller rotor speeds, meaning that the slicing time was oppositely correlated with rotor speed however closely associated with the feed rate of turmeric rhizome.

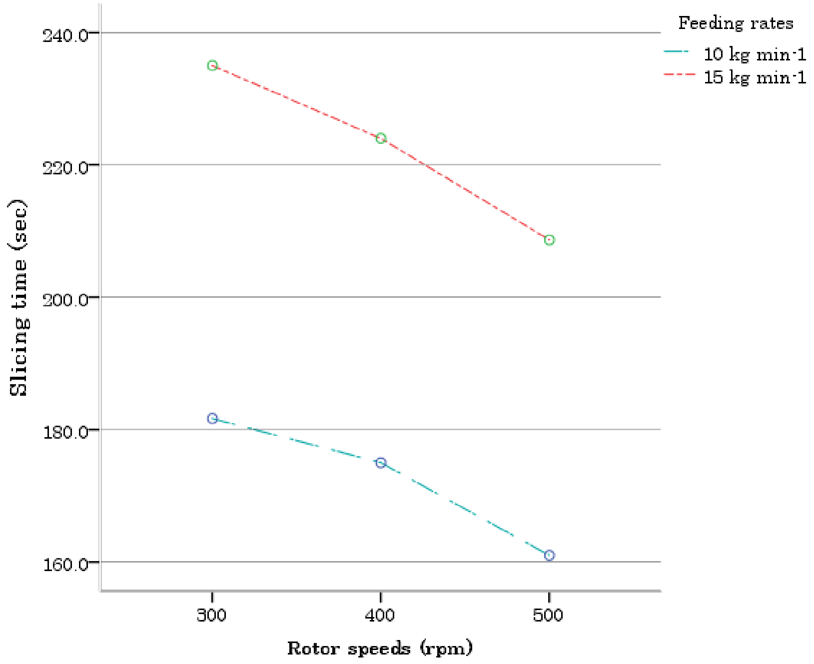

Figure 6*. Impact of rotor speed and feed rate on slicing time*

The rotor speeds of 500 rpm besides a feeding rate with 10 kg min^{-1} resulted in a minimum slicing time of 161 sec, while the rotor speeds of 300 rpm besides a feeding rate with 15 kg min^{-1} resulted in a maximum slicing time of 235 sec based on test results. Slicing time was reduced from 235 seconds to 161 seconds with higher rotor speeds of 300 rpm to 500 rpm.

Comparisons test of dependent variables for treatments

The LSD all pairwise comparison tests for slicing capacity, slicing efficiency, and material loss were carried out for each treatment as given below in Table 6 then this analysis was subjected to LSD all pairwise comparison tests for dependent variables for three levels of rotor speeds and two levels of feed rates to know significant differences among treatment means. So, LSD all pairwise comparison tests showed (Table 6) that there were four groups (a, b, etc.) whose treatment means were not significantly different from one another at the 5% level.

Table 6. *Mean separation of variables for treatments.*

No.	Treatments	Rotor speeds (rpm)	Feed rate (kg min^{-1})	Capacity (kg h^{-1})	Efficiency (%)	Material loss (%)
1	S1F1	300	10	722.19^{d}	93.867^{b}	7.6333^{a}
2	S1F2	300	15	714.97^{d}	94.033^{b}	7.4533^{a}
3	S2F1	400	10	747.37^{c}	94.1^{b}	7.4^{a}
4	S2F2	400	15	749.60^{c}	96.387^{a}	5.1^{b}
5	S3F1	500	10	824.77^{a}	96.933^{a}	4.566^{b}
6	S3F2	500	15	799.43^{b}	97.433^{a}	4.06^{b}
7	Grand mean			759.72	95.5	6.04
8	CV			0.86	0.95	15

S = Speeds, F = feed rate, CV = Coefficient of variation

Cost estimation

The costs of various parts as well as additional expenses were computed for estimating the costs associated with motorized turmeric-slicing machine. By applying farm machinery cost estimation techniques, depreciation, interest on capital, electric costs, wages, lubricant costs, repair and maintenance costs, tax, and insurance have been estimated as 6.4, 5.2, 0.93, 25, 0.51, 1.8, and 0.49 ETB h^{-1}, respectively. The turmeric slicer for slicing fresh turmeric rhizomes was found to have production costs of 56,324 Ethiopian birr. The motorized turmeric slicer machine was predicted to return for itself in a duration of ten to eleven months, or ten plus six months. The same pattern of cost estimation for root crop slicer was reported by Kunta (2018). A similar trend for root crop slicers was reported by Singh (2016). A comparable relation for root crop slicers was observed by Katanga (2022).

CONCLUSION

The turmeric slicer's evaluation was assessed at three different rotor speed settings and two different feeding rate settings at mean moisture contents of 48% at the wet basis for fresh turmeric rhizome Tepi-1 (Bonga 51/71) variety. The slicer underwent evaluation in terms of material loss, slicing efficiency, and slicing capacity. Studies revealed that understanding the physical characteristics of the turmeric rhizome was crucial for post-harvest tasks like material handling, testing, and processing. According to determination results, geometric mean diameter, arithmetic mean diameter, square mean diameter, equivalent diameter, aspect ratio, sphericity, shape factor, bulk density, porosity, coefficient of friction, and angle of repose were found to be 23.9 mm, 30.3 mm, 45.3 mm, 33.2 mm, 0.33, 0.4, 1.8, 336 kg m^{-3}, 81.7%, and 28.4°, respectively. The results of the evaluations showed that as rotor speeds raised from 300 rpm to 500 rpm, the slicing capacity rose from 714.9 kg h^{-1} to 824.7 kg h^{-1}, the slicing efficiency rose from 93.9% to 97.4%, and the material loss reduced from 7.6% to 4.06%. According to the results, the slicer machine's performance indicators were affected by rotor speeds and feed rates but were not affected by their interactions except slicing capacity.

DECLARATION OF COMPETING INTEREST

The author declares that there is no conflict of interest.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The author declared that the following contributions is correct.

Amanuel Erchafo Ertebo: Investigation, methodology, conceptualization, formal analysis, data curation, validation, writing-original draft, review, editing, and visualization etc.

ETHICS COMMITTEE DECISION

This article does not require any Ethical Committee Decision.

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