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EVALUATING THE PERFORMANCE OF THE CARROT SLICER MACHINE

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Abstract: The study was carried out to evaluate the performance of the carrot slicer machine. An experiment was conducted with a multi-factor factorial design under a randomized complete block design. Using the Statistix 8 software, the experiments' collected data were statistically examined. The analysis of variance indicated that the effects of machine speed and feed rate on throughput capacity, efficiency, and percentage loss of the machine were significant at the 5% probability level. The results of the least significant difference pairwise comparison tests revealed that the treatment combination means did not differ significantly from one another at the 5% level. The key physical properties of the carrot including moisture content, angle of repose, bulk density, porosity, coefficient of friction, geometric mean diameter, arithmetic mean diameter, equivalent mean diameter, sphericity, surface area and aspect ratio were obtained as 84.3%, 39.4°, 469.5 kg m^{-3}, 59.8%, 0.78, 47.8 mm, 62.18 mm, 83.7 mm, 0.55, 57.67 cm^2, and 0.27, correspondingly. The results showed that the maximum throughput capacity of 621.4 kg h^{-1} was recorded at 550 rpm machine speed while the minimum throughput capacity of 511.6 kg h^{-1} was recorded at 350 rpm machine speed. It has been found that the maximum machine efficiency was 96.03% at 550 rpm machine speed whereas the minimum machine efficiency was 92.5% at 350 rpm machine speed. The investigation results revealed that the minimum percentage loss was 4.2% at 550 rpm machine speed whereas the maximum percentage loss was 7.8% at 350 rpm machine speed. The test results suggested that the carrot slicer machine was found to be very effective for processing the vegetable root crop of carrots for end users.

Keywords: Carrot, Carrot slicer, Evaluation, Performance indicators, Physical properties

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1. Introduction

Carrot (*Daucus carota L.*) is a type of vegetable plant that belongs to the Apiaceae family and grows throughout the globe. It is one of the top ten vegetable crops in the entire world in terms of economic significance (Simon, 2021). Carrots are one of the most widely consumed agricultural products by millions of people worldwide (Nagraj et al., 2020). It is also a vital agricultural export that is good for a large number of global nations (Tabor and Yesuf, 2012)

Carrots have long been a mainstay of potlucks, get-togethers, and even snack time. They are dependable vegetables that are very adaptable and essential to vegetable trays. It is a useful food crop that is frequently eaten by the general public in the form of fresh veggies or drinks containing juice, as well as processed into various culinary delights (Ikram et al., 2024). Because it can be made into a variety of food products, the adaptable crop known as carrot is essential in tropical climates (Paparella et al., 2024b). It is regarded as a vegetable that is essential to global food security and the advancement of human health and well-being (Sharma et al., 2023).

Carrots are a highly valued root vegetable used extensively in cooking, raw, and juice forms (Ahmad et al., 2019).

The many health benefits of carrots include potential improvements to blood sugar regulation, weight management, cancer risk reduction, blood pressure regulation, heart disease prevention, immunity building, and brain health (Varshney and Mishra, 2022). Carrot cakes, cookies, and mashed carrots are just a few of the snacks that use carrot as a main ingredient. Carrots are mostly used as vegetables but can also be found in some limited supply as snacks like carrot chips. Carrot slices and chips are made by frying, drying, or baking (Laily et al., 2023). In addition to being a fantastic source of minerals and antioxidants, carrots are an intriguing source of carotenoids, vitamins, and dietary fiber. Carrots are a common food because they are an inexpensive source of vitamins, especially vitamin A, minerals, and fiber for the human diet (Ikram et al., 2024). Carrots are root vegetables that are typically orange in color, though they can also be red, white, yellow, or purple in appearance.

In tandem with the growing world population, there has been and is expected to be a continued increase in the demand for carrots. On an area of 1,137,738 ha, an average of 42,158,403 tonnes of carrots and turnips are produced globally each year, with an average yield of 37 tons per hectare (Papoutsis and Edelenbos, 2021). Asia accounted for about 61.8% of global carrot production, with Europe coming in second with 22.6%, the Americas third with 9.1%, and Africa contributing 5.4% (Ahmad et al., 2019). China presently contributes worldwide in the generation and consumption of carrots; the country harvests nearly half of the world's 42 million tons of carrots, through considerably China is surpassed by the United States of America, Uzbekistan, and Russia. Global consumption of turnips and carrots in 2020 was 46.3 million metric tonnes (Hamed and Mohamed, 2023).

In Ethiopia, carrots are grown in a variety of agro-ecologies, from the lowlands to the highlands (Fufa et al., 2020). The Shewa province and the central-northern regions surrounding Addis Ababa are the main production areas. Most developing countries, including Ethiopia, whose average fresh carrot yield per hectare is 5.6 t, have carrot yields per unit area that are lower than the average worldwide (Muhie and Yimer, 2023). Ethiopia's high altitude of 1800 to 2,500 meters above sea level makes it a promising place to produce premium carrots. During the growing season, carrots need 500 mm of evenly-spaced rainfall. 16 to 21 degrees Celsius are suitable for growth. It needs sandy to loamy, deep, loose, well-drained soils with a pH of 6 to 6.5. Grown from seed, carrots can reach maturity in as little as four months; however, in ideal circumstances, most cultivars reach maturity in 70–80 days (Noor, 2020).

Postharvest problems related to carrots include the most common storage decays, which include watery soft rot, sour rot, gray mold rot, bacteria soft rot, and Rhizopus soft rot (Papoutsis and Edelenbos, 2021). The shelf life of freshly harvested carrots is usually 3 to 4 weeks at 0 °C and 2 to 3 weeks at 3 to 5 °C (Asgar, 2020). While each variety of carrot crop has a different potential for storage, in general, fresh carrots don't keep well. Traditional methods may produce uneven drying or infected dried slices because the slices are not uniformly produced. Because manual slicing requires a lot of labor, takes a long time, and is prone to human error, the thickness and dimensions of the slices produced are erratic (Alabi et al., 2023).

The purpose of processing or slicing carrot crops is to extend shelf-life and shorten the drying period by increasing the surface area's exposure to air. The majority of processed root products must have their moisture content reduced to a point where microorganisms cannot grow there to be preserved (Leneveu-Jenvrin et al., 2022). A substitute for storing produce in its fresh state is to process it into staple, non-perishable, and transportable forms. The best way to preserve carrots for human consumption is to process them into flour, chips, and pellets while they are dried (Haq and Prasad, 2015). Before being cooked and steam-tested, carrots are frequently sliced, either for immediate consumption or as a first step in a processing system. Carrot crops are processed through a series of size-reduction steps, such as washing, peeling, chipping, slicing, and drying.

Nowadays, machine processing is increasingly supplanting manual processing because life for people is becoming more competitive and fast-paced Technology-induced automation has significantly reduced the amount of time and effort that humans must spend. The use of carrot slicer machines by consumers to cut vegetable carrots has become more and more important as technology has advanced. The necessity of using a slice machine to slice carrot crops arose from the increased demand for these crops for a variety of household purpose. Therefore, the main objective of this study was to assess the vegetable root crop carrot slicer machine's performance to reduce the technology disparity in carrot processing in Oromia regions that produce carrots, make the carrot slicer available for upcoming involvements, and provide the performance indicating data about machine for end users.

2. Materials and Methods

2.1. Study Area

The study of the evaluating the carrot slicer machine's performance was conducted at the Melkassa Agricultural Research Center, which is situated 17 km southeast of Adama town and 117 km east of Addis Ababa in the Adama Woreda, East Shewa Zone, Oromia Regional State, close to the town of Awash Melkassa. At 1560 meters above sea level, it is located between 8° 24' 0" and 8° 30' 12'' N and 39° 21' 0" and 39° 35' 14'' E. The average yearly rainfall is 763 mm, and the average high and low temperatures are 28.4 °C and 14 °C.

2.2. Machine Description

The carrot vegetable crop slicer machine (Figure 1) was driven by a 3.73 kW motor which revolves at a continuous machine speed. The main components of the carrot slicer machine are the feed inlet, cover, disc, cutting blade, blade holder, chute, main frame, engine set, shaft, pulley, V-belt, and motor. The mainframe is the unit of the machine on which all other components of the machine were supported. All of the machine's other parts are supported by the main frame. Mild steel was used to fabricate the other components, while stainless steel was used for the processing portion that came into direct contact. The carrot vegetable crop slicer machine is simple to use, requires only two operators to manage the entire process, and is less complicated to operate. For farmers who grow carrots as a vegetable crop, this carrot vegetable crop slicer machine was a great option because of its easy-to-use mechanism. For small-scale farmers working alone or in groups, the carrot slicer machine was cost-effective, endured for an extended period, sliced carrots uniformly, and was sufficiently quick.

Figure 1. Carrot slicer machine.

2.2.1. Working principles

The carrot slicer machine is operated by an electric motor and power is transmitted to the blades through the shaft via the pulley's V-belt. Before it is operated, all the parts must be properly set and fixed together. The slicing machine works by using a combination of a rotating blade and manual feeding to cut material into slices. As the shaft rotates, it turns the slicing disc in the anti-clockwise direction. The rotation of the slicing disc would perform an impact action on the root and the sharp blade would cut the tubers by impact shear force to the designed thickness. The centrifugal force of the rotating disc forced the fallen root on a fixed cutter to accomplish the slicing process. The clearance between the casing plate and the fixed cutting stainless steel blade was adjusted to get slices of the desired thickness.

The clearance on the blade predetermines the thickness of the slices and this is greatly enhanced by the rotating speed of the blade. The roots are manually fed through the inlet by the operator against the rotating blades and to be sliced to meet the rotating blade. This directs it to the slicing disc then the sliced chips then proceed to the discharge chute by gravity where they are collected into the receptacle below the outlet. During working the slicer, to prevent the carrot slice from being flown away by the effect of centrifugal force on the cutting blade, a circular disc cover was provided which helps to direct the chips through a discharge chute.

2.2.2. Cutting unit and its shape features

The cutting blades (knife type) are sharpened at one side and were positioned at a tension through adjustable screws and bolts to prevent. It was made up of stainless steel material with a dimension of 300x60x6 mm. Stainless steel blades are suited for everyday use and can slice both hard and soft crops. The 18° champers were given to make edges sharpened. Each of the blades has holes of Ø 6 mm at one end to facilitate bolting it to the circular disc of diameter 500 mm. The blade holder rotated continuously at the face of the disc when the carrot came in contact with blade holder it sliced the carrot to a precise thickness. The thickness of the slices is predetermined by the clearance on the blade to the fixed disc and this is greatly enhanced by the rotating speed of the blade. The centrifugal force of the rotating disc forced the fallen root on a fixed cutter to accomplish the slicing process. The operation could be based on a slicing blade as the processing unit. The clearance between the casing circular plate and the fixed cutting stainless steel blade was adjusted to get slices of the desired thickness.

Cutting units or blades of slicer can have a variety of shapes and features, including straight, circular, curved, and custom shapes. A cutting blade's shape features depend on the blade type, desired cutting performance, and the intended task. In this case, a straight blade was selected, considering the sharpening's ease and availability. The slicer cutting unit or blade considers the following shape features: the edge of the blade, can be straight; the blade angle, can vary over the curvature of the blade to achieve different accelerations of the slice and blade material, which should be appropriate for the cut material, hardness, wear resistance, and environment.

2.3. Materials

The carrot crop sample was taken from the Kulumssa Agricultural Research Center experimental field in the east-western regions of Oromia, east Arsi, to compute the physical attributes and conduct comprehensive tests on the carrot slicer machine. A Nantes-variety vegetable carrot crop served as the experiment's resources. Since it is readily available and has a high production capacity in the chosen area as well as other growing regions of Ethiopia, this variety ought to be chosen. The most popular variety in Ethiopia is Nantes as well.

2.4. Device for Measurement

In the experiment, a digital tachometer, tape measure, digital Vernier caliper, and digital weighing scale were utilized. Several measurements were taken of the carrot crops using these different instruments. The vegetable carrot crop's length and dimensions were measured with a tape measure. The minimum length that this measuring tool can measure is 5 mm. We used a Vernier caliper with a resolution of 0.01 mm to measure the carrots' diameters and thickness. The mass of the carrot could be measured using the digital scale both before and after processing. This 0.01 g accurate digital scale (GF600, USA model) was utilized. A non-contact kind of tachometer was used to measure the speeds of the slicer machine. With a measurement range of 2 r min^{-1} to 99,999 r min^{-1} and a measuring distance of 50 mm to 500 mm, this tachometer has a sensitivity of 0.044 v rad sec^{-1}.

2.5. Methods

2.5.1. Determining physical properties of carrot (*Daucus carota L.*)

Studies on the different important physical characteristics of carrots have provided important information essential for the design and development of processing machinery and equipment for sorting, washing, grading, processing, and cleaning (Nithyalakshmi, 2024). Determining the physical characteristics of agricultural materials is crucial for designing conveying machinery and processes, feed hoppers, metering systems, and storage facilities (Fred, 2014). It also necessitates knowledge of how to turn these materials into products. The characteristics of carrots are helpful when designing equipment for processing, handling, and storing them. These physical characteristics are essential for designing the carrot slicer's hoppers and outlets.

The carrots used in this study were harvested when they reached their maximum ripeness. From 25 to 100 carrot samples were chosen at random to determine each of the physical characteristics of the carrot, including its moisture content, angle of repose, bulk density, porosity, coefficient of friction, geometric mean diameter, arithmetic mean diameter, equivalent mean diameter, sphericity, surface area and aspect ratio. The following characteristics of carrots were studied:

Weight was reached. Then, the moisture content of carrot fruit was calculated by Equation 1.

$$Mc = \frac{Mw - Md}{Mw} \times 100 \quad (1)$$

where Mc is the moisture content of carrot (%), M_w is the initial mass of carrot (g), and M_d is the mass of dried carrot (g).

Angle of repose

One of the key parameters for identifying the machine's convening component is the angle of repose. The carrot sample's radius (r) and one opposing side (L) formed a conical shape, which was used to calculate the angle of repose. The angle formed by the carrot and the horizontal surface when piled from a known height is also known as the angle of repose. The angle of the repose for carrot fruit was calculated by the formula given in Equation 2 (Nithyalakshmi, 2024).

$$\theta = cos^{-1}\frac{r}{l} \quad (2)$$

where Θ is the angle of repose in (°), l is the height in (cm), and r is the radius of conical shape in (cm).

Bulk density

The bulk density was calculated by dividing the volume of a container by the mass of carrot fruit per unit. A measuring cylinder was filled with carrots, and the volume of the carrots was then calculated. The bulk density of the carrot was calculated using the following formula (Nithyalakshmi, 2024) given in Equation 3.

$$\rho_b = \frac{M}{V} \quad (3)$$

where ρ_b is the bulk density of the carrot (kg m^{-3}), M is the mass of the carrot (kg), and V is the volume of the carrot (m^{-3}).

Porosity

Porosity was determined by dividing the fruit density value by the difference between the fruit and bulk densities, expressed as a percentage, as per methodologies described by (Vursavuş et al., 2006) as given in Equation 4:

$$\varepsilon = \frac{\rho_f - \rho_b}{\rho_f} \quad (4)$$

where ε is the porosity, ρ_b is the bulk density, and ρ_f is the fruit density.

Coefficient of friction

The coefficient of static friction is crucial for the carrots to slide or move. Carrot surfaces are kept from moving when they come into contact with a machine convening part by the frictional force ratio. The coefficient of friction for carrot related different surfaces namely stainless, galvanized and mild steel can be calculated using Equation 5 (Nithyalakshmi, 2024).

$$\mu S = \frac{Sin\theta}{Cos\theta} \quad (5)$$

where μs is the coefficient of static friction.

Geometric mean diameter

Utilizing the major length (L), width (W), and thickness (T), the cub root of the carrot fruit was used to express the geometric mean diameter, which was taken into consideration as the size criterion. An average amount for the geometric mean diameter of the carrot can be determined using Equation 6 (Jahanbakhshi et al., 2018).

$$D_g = \sqrt[3]{L \times V \times T} \quad (6)$$

where D_g is the geometric mean diameter (mm), L is the major length (mm), W is the width (mm), and T is the thickness (mm).

Arithmetic mean diameter

The Arithmetic mean diameter of carrot fruit samples was determined using the formula (Jahanbakhshi et al., 2018) in Equation 7.

$$D_a = \frac{(L + T + V)}{3} \quad (7)$$

where D_a is the arithmetic mean diameter (mm), L is the major length (mm), W is the width (mm), and T is the thickness (mm).

Equivalent mean diameter

The equivalent mean diameter of carrot fruit samples was determined using the formula (Jahanbakhshi et al., 2018) given in Equation 8.

$$D_e = \frac{(D_g + D_a + D_s)}{3} \quad (8)$$

where D_e is the equivalent mean diameter, D_g the is geometric mean diameter (mm), D_a is the arithmetic mean diameter (mm), and D_s is the square mean diameter (mm).

Sphericity

The ratio of the carrot's surface area to the surface area of a sphere with the same volume as the carrot fruit is termed its sphericity. The sphericity of carrot fruit samples was determined using the formula by (Jahanbakhshi et al., 2018) given in Equation 9.

$$\Phi = \frac{D_g}{L} \quad (9)$$

where Φ is the sphericity of the carrot (mm), D_g is the geometric mean diameter (mm), and L is the major length (mm).

Surface area

To calculate the surface area, the carrot's four sides were traced on a graph sheet, and the number of squares inside the traced outline was counted. The surface area for the carrot were determined as per the following Equation 10 (Nithyalakshmi, 2024).

$$S = \pi D_g^2 \quad (10)$$

where S is the surface area (mm^2), and D_g is the geometric mean diameter (mm).

Aspect ratio

It was calculated as the ratio of the width of carrot fruit to the major length of carrot fruit then it can be determined by the expression as reported by (Jahanbakhshi et al., 2018) as given in Equations 11.

$$R_a = \frac{W}{L} \times 100 \quad (11)$$

Where R_a is the aspect ratio, L is the major length (mm) and W is the width (mm).

2.6. Experimental Procedures

The experimental sample of carrots was cleaned and washed by hand to eliminate adhering soil, hairs and extraneous matter before slicing it. An electronic balance was used to measure the mass of each type of carrot crop, and each sample was fed into the slicer machine through the feeding inlet in a specific way while the machine operated at different preset machine speeds. The test materials were manually pushed through the inlet into the slicing unit, where they were then sliced to the appropriate thickness by pushing them up against the cutting blade. The carrot slicer's effectiveness could have been evaluated throughout the experiment using the full weight of 320 kg of carrot crop. The machine's ideal speed was ascertained through preliminary testing. A tachometer was used to set the machine speeds to 350, 450, and 550 rpm after the carrot slicer was powered on. These speeds were selected by (El-Haq et al., 2016) to test the machine's performance on carrot fruit.

2.7. Performance indicators

The evaluation was performed on a carrot slicer machine in terms of performance indicators to predetermine the machine's effectiveness at different levels of machine speed and material feed rate. After being collected from the machine outlet, the output materials were divided into two categories: sliced and unsliced. An electronic balance was used to determine each category's mass. A stopwatch was used to record the amount of time needed for each test run. The throughput capacity, machine efficiency, percentage loss, and time required to forecast the machine's performance were all taken into account when evaluating the machine. The test parameters such as throughput capacity, machine efficiency, percentage loss, and time taken for carrot slicer were assessed utilizing the following formulas given in Equations 12-14 by Ezeanya (2020).

$$\text{Throughput capacity (kg h}^{-1}\text{)} = \frac{W_f}{t} \quad (12)$$

$$\text{Machine efficiency} = \frac{W_c - W_n}{W_c} \times 100 \quad (13)$$

$$\text{Percentage loss} = \frac{W_i - W_c}{W_i} \times 100 \quad (14)$$

where W_f is the weight of the total sliced carrot in (kg), t is the time required to slice carrot in (h), W_c is the weight of carrot collected in (kg), W_i is the weight of carrot feed in (kg), and W_n is the weight of a non-uniform slice in (kg).

2.8. Statistical analysis

An experiment was carried out with a multi-factor factorial design under a randomized complete block design and the levels of machine speed with feed rate levels were taken as treatment combinations for an experiment. As independent variables or factors, the material feed rate and machine speed were taken into account. Each treatment is replicated three times in this experiment (3x2x3 = 18). Using the Statistix 8 software, the experiments' collected data were statistically examined. The 95% confidence interval was utilized to demonstrate the significant impact of independent variables on dependent variables. The least significant difference was used at the 5% level to compare the treatment means. An analysis of variance (ANOVA) was used to test the effects of the experiment.

3. Results and Discussion

3.1. Physical Properties of Carrot (*Daucus carota L.*)

As Table 1 shows, the Nantes variety of carrot crop samples' mean, deviation, maximum, and minimum value for moisture content, angle of repose, bulk density, porosity, coefficient of friction, geometric mean diameter, arithmetic mean diameter, equivalent mean diameter, sphericity, surface area and aspect ratio were calculated. The findings showed that, on a wet basis, the mean moisture content of the carrot was 84.3% with standard deviations of 2.06 and 81.7% to 86.7% was the range of this moisture content. The vegetable root crop of carrot had a mean angle of repose of 39.4° with a standard deviation of 1.08, and a range of 38° to 40.8°.

The findings showed that the bulk density of the carrot crop ranged from 456.8 to 480.6 kg m^{-3}, with a mean and standard deviation of 469.5 kg m^{-3} and 10.6, respectively. The carrot porosity varied from 65% to 53%. The calculated mean porosity was 59.8% with a standard deviation of 5.12. The average static coefficient of friction for carrot crop on stainless, galvanized, and mild steel surfaces was 0.78, 0.82, and 0.87 with standard deviations of 0.06, 0.03, and 0.05, respectively.

The carrot crop varied in length from 133 to 191 mm, width from 27.1 to 39.4 mm, and thickness from 30.8 to 38.4 mm, according to the results. The mean values for thickness, width, and length were found to be 34.5 mm, 33.06 mm, and 161.8 mm, respectively. The calculated values of the standard deviation were 2.83, 4.53, and 24.3. The findings indicated that the geometric mean diameter of carrot ranged from 42 mm to 53.7 mm. The corresponding mean values and standard deviations were found to be 47.82 mm and 4.64. Additionally, the arithmetic mean diameter ranged from 55 mm to 76 mm as well as the mean values of 62.18 mm and standard deviations of 7.39 were found. Between 80.9 and 87.3 mm was the range of the equivalent mean diameter moreover, the standard deviations and mean values were 2.54 and 83.7 mm, respectively.

The sphericity of the carrot ranged from 0.49 to 0.59, with corresponding means and standard deviations of 0.55 and 0.04. The carrot crop surface area was determined to be between 46 and 69 cm^2 with means and standard deviations of 57.67 cm^2 and 9.66. The range of aspect ratios for carrot crops was 0.21 to 0.34, additionally, the computed mean value and standard deviations were found to be 0.27 and 0.05, respectively. Nithyalakshmi (2024) noted a similar pattern for the property of carrot fruit.

The results showed that slicing worked better when vegetable carrots had a higher moisture content. According to the test, the most important element preserving the carrot crop's capacity to be sliced was its moisture content. The obtained angle of repose indicated that to feed the carrot on the machine simultaneously, a small inclination was needed at the discharge chute. It was very helpful for conveying systems, processing equipment, handling and development of machine to examine the physical properties of the vegetable crop of carrot. A similar pattern was observed by Nithyalakshmi (2024) regarding the carrot fruit's properties.

3.2. Evaluation of the machine

The performance of the machine was evaluated based on the speed of the machine and the material feed rate at which it cleans on a variety of carrots. The tests were repeated thrice, and the outcome was measured in terms of the machine's performance indicators. The carrot slicer was evaluated in terms of throughput capacity, machine efficiency, percentage loss, and time required at a mean moisture content of 84.3% at the wet basis for vegetable root crop carrot Nantes variety at three different machine speed levels and different feed rate levels. Weighing of the entire sliced carrot, the weight uniformly sliced carrot, the weight non-uniformly sliced carrot, and the time requirement were recorded after the machine finished processing the carrot crop.

Table 1. Various physical characteristics of carrot

Properties of carrot	N	Mean value	SD	Mean±SD	Max	Min	CV
Mass (g)	100	122.2	85.9	122.2 ±85.9	221	26	32
Moisture content (%)	60	84.3	2.06	84.3±2.06	86.7	81.7	2.4
Angle of repose (°)	40	39.4	1.08	39.4±1.08	40.8	38	2.8
Bulk density (kg m^{-3})	50	469.5	10.6	469.5±10.6	480.6	456.8	2.3
Porosity (%)	36	59.8	5.12	59.8±5.12	65	53	8.5
Coefficient friction							
Stainless steel	45	0.78	0.06	0.78±0.06	0.84	0.7	7.6
Galvanized steel	45	0.82	0.03	0.82 ±0.03	0.85	0.79	3.5
Mild steel	45	0.87	0.05	0.87±0.05	0.91	0.83	5.3
Geometric mean diameter (mm)	30	47.82	4.64	47.82±4.64	53.7	42	9.7
Arithmetic mean diameter (mm)	30	62.18	7.39	62.18±7.39	76	55	11.8
Equivalent mean diameter (mm)	30	83.7	2.54	83.7±2.54	87.3	80.9	3.0
Sphericity	40	0.55	0.04	0.55±0.04	0.59	0.49	7.6
Surface area (cm^2)	32	57.67	9.66	57.67±9.66	69	46	16.8
Aspect ratio	25	0.27	0.05	0.27±0.05	0.34	0.21	17

Table 2. Analysis of variance for throughput capacity

Source	DF	Sum of squares	Mean squares	F-value	P-value
Replication	2	4.96	2.48		
Machine speed	2	27263.4	13631.7	326.58	0.000
Feed rate	1	448.7	448.7	10.75	0.006
Speed ×Feed	2	576.5	288.25	6.9	0.012
Error	10	417.4	41.74		
Total	17	28710.96			

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

It was observed during the test that the machine cut the carrot crop into slices that were between 3 and 5 mm thick. The test results showed that the carrot slicer machine was found to be very effective for processing the vegetable root crop of carrots.

3.2.1. Effects of machine speed and feed rate on throughput capacity

Table 2 shows the results of the analysis of variance for the effects of machine speed, material feed rate, and their interaction on the throughput capacity of the carrot slicer machine. According to the results, analysis of variance showed that material feed rate, machine speed, and their interactions had significant effects at a 5% probability level because the p-values were less than 0.05 (Table 2). The findings indicated that the output of a machine was influenced by feed rate, machine speed, and their interaction effect.

As shown in Figure 2, the machine's mean throughput capacity ranged from 511.6 kg h^{-1} to 621.4 kg h^{-1} when the machine speed increased from 350 rpm to 550 rpm. As increasing the throughput capacity from 511.6 kg h^{-1} to 621.4 kg h^{-1} while the material feed rate caused the machine output capacity to decrease then machine speed caused it to increase. This finding revealed that the throughput capacity had a direct relationship with the machine speed and an inverse relationship with the feed rate of carrot crop.

The results showed that the maximum throughput capacity of 621.4 kg h^{-1} was recorded at 550 rpm machine speed and 10 kg min^{-1} material feed rate, while the minimum throughput capacity was recorded at 350 rpm machine speed and 15 kg min^{-1} feed rate of material. There were previous studies in the literature relating to slicing machines capacity for carrot crop.

Tanwar et al. (2021) reported similar findings for slicer machine capacity. Ezeanya (2020) reports the throughput capacity of the machine ranged from 20.52 to 44.28 kg h^{-1}, during evalutating the slicer. Agbetoye and Balogun (2009) reported a capacity of machine as 48.9 kg h^{-1} when assessing slicer performance for slicing the carrot.

3.2.2. Effects of machine speed and feed rate on efficiency

Table 3 displays the results of the analysis of variance for the effects of machine speed, feed rate, and their interaction on the efficiency of the machine. The analysis of variance indicated that the effects of machine speed and feed rates were significant at the 5% probability level as given (Table 3) that the p values were less than 0.05 and the interaction effects were non-significant (P>0.05). Regardless of the outcome, feed rate and machine speed, excluding their relative interactions, had an impact on the machine's efficiency.

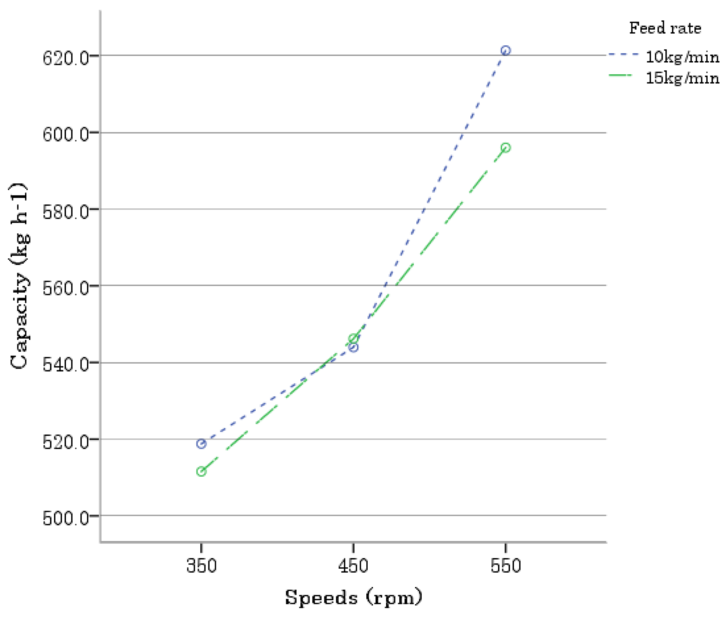

Figure 2. Effects of machine speed and feed rate on throughput capacity.

Table 3. Analysis of variance for machine efficiency

Source	DF	Sum of squares	Mean squares	F-value	P-value
Replication	2	0.0156	0.0078		
Machine speed	2	30.5613	15.2807	21.46	0.0002
Feed rate	1	4.2522	4.2522	5.97	0.0330
Speed ×Feed	2	3.7876	1.894	2.66	0.1224
Error	10	7.1157	0.712		
Total	17	45.7324			

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

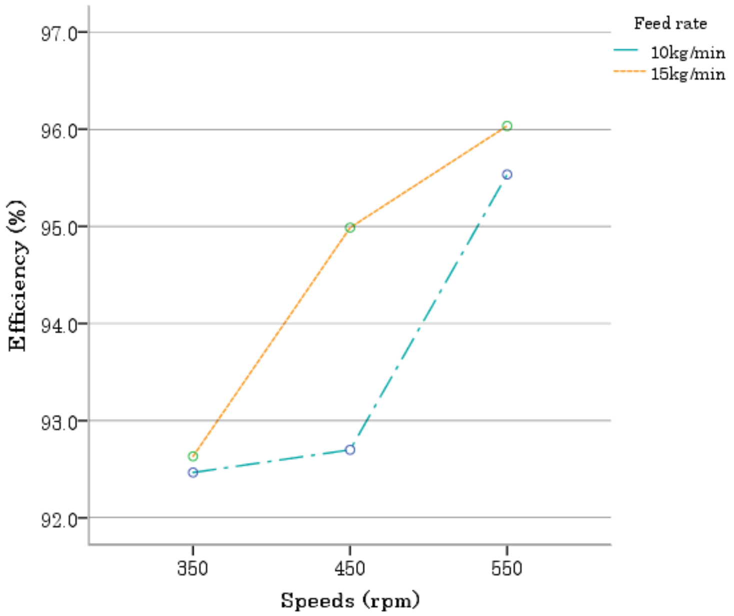

Figure 3. Effect of machine speed and feed rate on machine efficiency.

Table 4. Analysis of variance for percentage loss

Source	DF	Sum of squares	Mean squares	F-value	P-value
Replication	2	0.0212	0.0106		
Machine speed	2	30.5325	15.2663	21.25	0.0003
Feed rate	1	4.3311	4.3311	6.03	0.0311
Speed ×Feed	2	3.8172	1.909	2.66	0.1215
Error	10	7.1836	0.71836		
Total	17	45.8856			

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

As shown in Figure 3, the test's findings showed that a machine's mean efficiency ranged from 92.5% to 96.03%. When machine speed increased from 350 rpm to 550 rpm, the machine efficiency increased from 92.5% to 96.03%. As machine speed and the material feed rate increased, the machine's efficiency was expected to increase as well. This suggests a clear relationship between the efficiency and the independent variable or machine speed and feed rate of carrot.

It has been found that the maximum machine efficiency was 96.03% at 550 rpm machine speed and 15 kg min^{-1} material feed rate, whereas the minimum machine efficiency was 92.5% at 350 rpm and 10 kg min^{-1} material feed rate. There were also previous investigation relating to slicing machines efficiency for carrot crop. Tanwar et al. (2021) reported the same trend for slicer machine efficiency. Ezeanya (2020) states the efficiency of machine ranged from 60.7 to 87.8% when testing the machine. Agbetoye and Balogun (2009) reported a efficiency of machine as 95.4% when assessing slicer performance for slicing the carrot.

3.2.3. Effects of machine speed and feed rate on percentage loss

Table 4 displays the results of analysis of variance for the effects of feed rate, machine speed, and their interaction on the percentage loss of the machine. According to the results, analysis of variance showed that the influence of feed rate and machine speed was significant at the five percent (5%) significance level because the P-values were less than 0.05, but the effect of their interaction was non-significant, meaning the result was greater than 0.05 as given (Table 4). The results demonstrated that feed rate and machine speed affected a machine's percentage loss when their interactions were uninvolved.

As shown in Figure 4, a machine's mean percentage loss ranged from 4.2% to 7.8% based on the test results. As the machine speed increased from 350 rpm to 550 rpm, the percentage loss decreased from 7.8% to 4.2%. The machine's percentage loss was expected to decrease as machine speed and the material feed rate rose. This suggests that the carrot crop feed rate and machine speed were negatively related with percentage loss.

The investigation results showed that the minimum percentage loss was 4.2% at 550 rpm machine speed and material feed rate of 15 kg min^{-1} whereas the maximum percentage loss was 7.8% at 350 rpm machine speed and feed rate of 10 kg min^{-1}. The test results revealed that the 550 rpm machine speed had a negligible percentage loss when compared to the other machine speeds. There were previous findings relating to percentage loss of machine. Ezeanya (2020) reports the percentage loss of machine was 10.9% during evalutating the slicer. Agbetoye and Balogun (2009) reported a percentage loss of machine as 8.7% when assessing slicer performance for slicing the carrot crop.

3.2.4. Effects of machine speed and feed rate on time

Table 5 displays the results of the analysis of variance for the effects of feed rate, machine speed, and their interaction on the time taken by the machine. An analysis of variance revealed that the interaction between machine speed and feed rate was non-significant (P > 0.05) whereas the effects of each were significant at the 5% probability level due to values for p smaller than 0.05 (Table 5). According to the outcome, feed rate and machine speed had an impact on the machine's time taken, but their impact interactions had no effect observed.

Figure 5 shows that when material feed at 10 kg min^{-1} with 550 rpm machine speed and at 15 kg min^{-1} with 350 rpm machine speed, the mean time taken of a machine varied between 106 and 180 seconds. The results specifically demonstrated that when machine speed increased and material feed rate decreased, the machine's time taken to process tended to decrease. This is because faster machine speed outperformed slower ones, indicating that the time taken was negatively connected with machine speed but strongly correlated with the rate at which carrot crop was fed.

Based on test results, a minimum time taken of 106 seconds was achieved with machine speed of 550 rpm and a material feed rate of 10 kg min^{-1}, while a maximum time taken of 180 seconds was achieved with machine speed of 350 rpm and a material feed rate of 15 kg min^{-1}. With higher machine speed of 350 rpm to 550 rpm, the time taken was shortened from 180 seconds to 106 seconds.

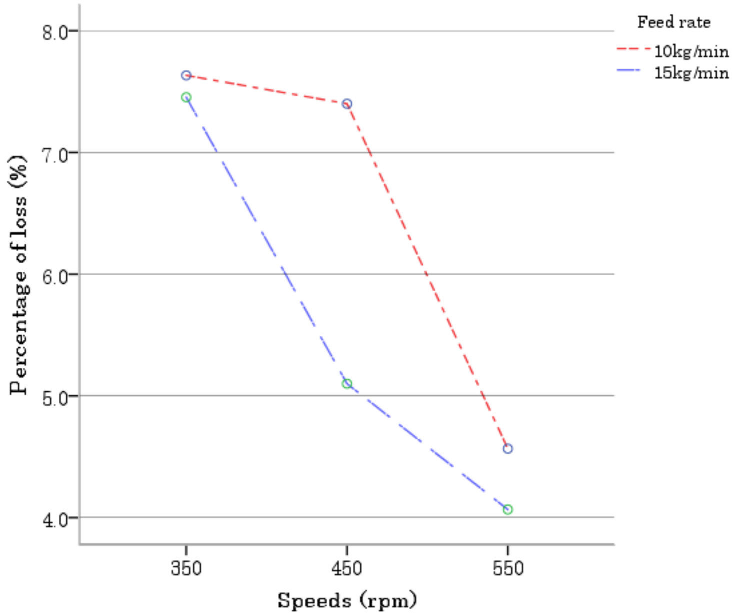

Figure 4. Effect of machine speed and feed rate on percentage loss.

Table 5. Analysis of variance for time taken

Source	DF	Sum of squares	Mean squares	F-value	P-value
Replication	2	0.3	0.15		
Machine speed	2	1571.6	785.8	116.07	0.000
Feed rate	1	11341	11341	1675.2	0.000
Speed ×Feed	2	25.1	12.55	1.854	0.146
Error	10	67.7	6.77		
Total	17	13005.7			

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

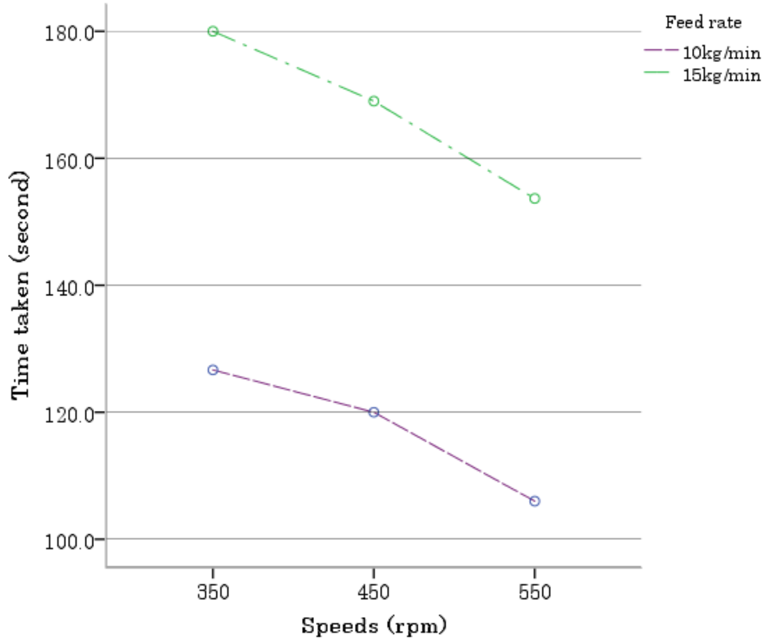

Figure 5. Effect of machine speed and feed rate on time.

Table 6. Comparisons of treatment means

No.	Treatment combination	Speeds (rpm)	Feed (kg min^{-1})	Throughput capacity (kg h^{-1})	Machine efficiency (%)	Percentage loss (%)	Time (sec)
1	V1F1	350	10	518.8^{D}	92.5^{B}	7.8^{A}	126.7^{D}
2	V1F2	350	15	511.6^{D}	92.6^{B}	7.6^{A}	180^{A}
3	V2F1	450	10	543.9^{C}	92.7^{B}	7.5^{A}	120^{E}
4	V2F2	450	15	546.2^{C}	94.98^{A}	5.3^{B}	169^{B}
5	V3F1	550	10	621.4^{A}	95.5^{A}	4.7^{B}	106^{F}
6	V3F2	550	15	596^{B}	96.03^{A}	4.2^{B}	153.7^{C}
7	Grand mean			556.3	94.06	6.5	142.6
8	CV			1.18	0.98	16	1.84

V = speed, F = feed rate, V1 = 350 rpm, V2 = 450 rpm, V3 = 550 rpm, F1 = 10 kg min^{-1}, F2 = 15 kg min^{-1} and CV = coefficient of variation.

3.2.5. Mean separation

Each treatment combination underwent the least significance difference all pairwise comparison tests for throughput capacity, machine efficiency, and percentage loss, as indicated below in Table 6. To determine whether there were significant differences between treatment means, this analysis was then subjected to least significance difference all pairwise comparison tests for dependent variables for levels of machine speed and for feed rates. The results of least significance difference's pairwise comparison tests indicated that, at the 5% level, the treatment combination means of four groups (A, B, etc.) did not differ significantly from one another at 5% probability level.

4. Conclusion

The carrot slicer performance was evaluated at three different machine speeds (350, 450, and 550 rpm) and different feed rate levels at a mean moisture content of 84.3% for the carrot Nantes variety. The performance was carried out in terms of throughput capacity, machine efficiency, percentage loss, and time requirement. It was very helpful for conveying systems, processing equipment, handling and development of machine studying the physical properties of the crop carrot. The key physical properties of the carrot including moisture content, angle of repose, bulk density, porosity, coefficient of friction, geometric mean diameter, arithmetic mean diameter, equivalent mean diameter, sphericity, surface area and aspect ratio were studied. The assessment's findings indicated that when machine speed increased from 350 to 550 rpm, the throughput capacity increased from 511.6 kg h^{-1} to 621.4 kg h^{-1}, the machine efficiency increased from 92.5% to 96.03%, and the percentage loss decreased from 7.8% to 4.2%. Analysis of variance showed that the carrot slicer machine's performance indicators were impacted by the main effects of feed rate and machine speed, but that throughput capacity was the only thing that was affected by their interactions.

Author Contributions

The percentage of the author contributions is presented below. The author reviewed and approved the final version of the manuscript.

	A.E.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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