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Designing and Manufacturing of Vegetable Slicing Machine

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ABSTRACT

Agro-processing industry is faced with a challenge of slicing of vegetables for immediate consumption. This stems from the fact that the traditional slicing methods use bare hands, and knives. This method is faced with shortcomings of inefficiency, poor hygiene, and significant dangers to injury. If vegetables are not sliced, their drying takes longer, may possibly be spoiled, and cannot be stored for future uses. Therefore, this paper strives to design a vegetable slicing machine to increase the efficiency of the drying process as a post-processing step. The study employed a Pugh's design model to design the machine and manufacture it. First, the necessary information for the design was collected. Thereafter, the machine was designed according to specifications – 0.5 hp, 1400 rpm motor; with a capacity of slicing of 30 kg/h, at an efficiency of 86%. The prototype was tested using carrots. The whole testing was conducted with no injury, and ease to the users. It is advised to automate the vegetable feeding process and reduce the size for future improvements of the vegetable slicing machine.

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INTRODUCTION

Immediate consumption of most vegetables is impossible, if their size is not reduced. This has been a problem of agro-processing industries. Slicing could be a solution to size reduction of vegetables, and as such, slicing vegetables is one of the most popular ways to reduce their size. Traditionally, vegetables are sliced using bare hands, and knives. This method is dangerous; and characterized by poor hygiene and low efficiency. The vegetables sliced are of varying sizes, and lack the quality appreciated by consumers.

To ameliorate this challenge, a vegetable slicing machine is important to be designed. Since vegetables are required to be sliced with regularity, this research will primarily focus on starchy vegetables, particularly roots and tubers.

A vegetable slicing machine is a tool that aids the slicing process while processing vegetables for direct consumption or processing for small-scale vegetable dealers. The traditional method of slicing vegetables has been criticized for some reasons, including inefficiency, sanitation and safety risks. According to NPHMS (2018), Tanzania loses up to 40% of its harvest due to post-harvest losses (PHLs). Vegetables are sliced to increase their surface area to facilitate the drying process which prolongs their shelf life. Unsliced vegetables tend to last for short moments compared to the sliced ones. There are several slicing devices in the market for home applications. Most of them are manually operated and are single vegetable-type devices which are cheap. When it comes to vegetable machine vendors, there are several machines at the the price range between TZS 800,000-2,000,000 quoted from Alibaba online. Which is not economical for small scale vendors. Most of the slicing machines that are currently available slice a single type of vegetable which necessitates multiple units for slicing different vegetables.

Therefore, this study aimed to design and manufacture a vegetable-slicing machine as well as evaluate the performance of the machine at the laboratory prototype level. To achieve this major question, three sub-research questions were formulated as follows:

a) What is the relevant information required to design a vegetable-slicing machine?
b) What are the requirements to design and manufacture vegetable-slicing machines?
c) How the performance of the vegetable slicing machine can be evaluated?

Literature Review

By emphasizing the use of stainless steel for health reasons, Ikpoza *et al.* (2021) designed a conventionally operated vegetable leaf-slicing machine. The efficiency of this machine was determined by the ratio of the size difference between the initial size of the vegetable and the final size of the slice, to the initial size of the vegetable, and it was discovered to be 95.52%. This was an improvement to the previous technique which involved vegetable slicing using bare hands and knives, which had an average capacity of 1.09 kg/h. Kahandage & Wathsala (2017) designed a vegetable slicing machine that was found to have a 1.717 kg/h capacity. Hoque & Saha (2017) designed a potato-slicing machine that is manually operated aiming to improve the efficiency and throughput of the process. The machine's capacity, and machine efficiency was determined by the ratio of the weight of the sliced vegetable to the initial weight of the vegetable before slicing, was found to be 42.93 kg/h with an efficiency of 88.8%.

Krantidip et al. (2020) developed fruit and vegetable slicing machine, with a capacity of 96 kg/h and efficiency of 70%. Salaudeen & Fidelis (2017) designed a motorized tomato slicer that uses a gravitational feeding system to feed tomatoes to rotating blades. The machine's capacity, and efficiency was found to be 468 kg/h and 60.34% respectively, with the usage of a 0.25 hp and 1200 rpm motor. It was suggested that the knife carriage be altered to be more robust for increased efficiency. Sonawane et al. (2011) designed a power-operated banana slicer for small-scale food processing industries focused on the cutter assembly. The assembly consists of the cutter plate and the cutter blade. A motor with a speed of 360 rpm was used. The machine's effective capacity was found to be 100 kg/h with an efficiency of 93%. Bello *et al.* (2017) developed a small-scale multi-crop chipper with a 1 hp motor and cassava as a testing sample. The machine capacity was found to be 53.58 kg/h with an efficiency of 86.15%. It was also discovered that the slicing capacity of the device is strongly influenced by the mechanical and physical characteristics of the vegetable as well as the machine's slicing unit arrangement. Gladys *et al.* (2018) stated that some machine parameters and crop parameters are factors that affect both the energy consumption and overall cutting efficiency. It was also stated that a cutting tool sharpened between 0^0 and 40^0 blade shape angle and cutting speed between 20 mm/min and 50 mm/min will yield minimum energy requirement during operation. Eliçin & Pekitkan (2019) claimed that cutting force rose with rising load speed, however, shear energy did not change with knife loading speed. Cutting force, strength, energy values, and specific energy values decreased with increasing knife cutting angle from 0^0 to 40^0

sharpening angle. A knife with a sharpening angle of 17.5^0 had the highest cutting force measurement, and a knife with a sharpening angle of 2.5^0 had the lowest cutting force measurement. A knife with a flat edge had the weakest cutting power and force. According to Ishola & Adewole (2020), an increase in the slicing disc's speed, increased both efficiency and throughput capacity, while mechanical damage decreased. That experiment produced the following results: the maximum value of slicing efficiency was 99.88%, the highest value of throughput capacity was 184.11 kg/h, and the mechanical damage index value reduced from 16.05% at 300 rpm to 0.30% at 1200 rpm.

METHODS AND MATERIALS

This was a mixed method study as both quantitative and qualitative techniques were employed to design and manufacture the vegetable slicing machine. Integration of customers' requirements and experts was important as it enabled the collection of product information.

Searching for More Information

Data were collected to acquire insight into the design, input from consumers (small-scale vendors) and technicians through observation and structured interviews.

Data Analysis

The information needed to determine design needs, wishes, and limits were taken from the data collected from the aforementioned information. Both qualitative and quantitative approaches were used to analyze the data collected.

Product Design

The machine was then designed with the consideration of information gathered and analysis. The following activities were performed to complete this part.

a) Based on the information gathered, the product design specification (PDS) for the design was generated.
b) Then PDS was used to generate three potential concepts for the machine design, and the rating and weighting matrix method was then used to select the best concept.
c) The chosen concept was then realized through a hand draft, followed by a design analysis and design draft.
d) The machine's design was completed after considering further information by creating detailed drawings of each functional component and an assembly drawing of the entire machine. All the drawings were generated through SolidWorks software.

Manufacturing and Testing of the Machine

A machine was built from the plan, built locally in workshops, and its materials were chosen based on technical and cost factors. Testing of the machine's performance in terms of slicing capacity with chosen parameters was accomplished. These parameters include slicing capacity and efficiency, motor rating power and speed. Testing vegetables used were carrots. The machine was tested for slicing capacity, and efficiency using a motor of 0.5 hp, 1400 rpm.

Design and Manufacturing

Embodiment Design

Product Design Specification

The vegetable slicing machine design specification is illustrated in Table 1, explaining many aspects.

Conceptualization

Three concepts created for the design using the generated PDS as a reference will be explained. The concepts will then be chosen for other design stages after being assessed and passing criterion for the concept.

The first concept is a reciprocating motion of the single blade. This will be used to slice vegetables which are fed on one side and collected on the other.

Table 1: Product design specification

Design specification	Description
1. Performance	✓ 150 kg of root or tuber vegetables should be cut into slices every day, or 12.5 kg/h. ✓ The thickness of the slice should be less than 3 mm. ✓ The product resulting noise should be below 83 dB for 12 h as per the Tanzania Bureau of Standards.
2. Product life span	✓ The product should function continuously for five years, 12 h per day, six days per week. ✓ The product life cycle should be determined by the trustworthiness of the product frame.
3. Customers	✓ Small-scale vegetable vendors are the product's primary target market.
4. Safety	✓ The product should weigh less, be smaller in size, have all moving parts covered, and have few to no edges.
5. Packaging	✓ The product should be packed as a fully assembled product. ✓ During storage and shipping, the product should be packed. ✓ The product must be packaged to protect it from shock, vibration, and water. ✓ Lightweight materials should be used to package the product. ✓ One packaging system should be used for all packages.
6. Cost of production	✓ The product's price should fall between TZS 200,000 and TZS 300,000. This includes the cost of materials and manufacture.
7. Weight	✓ For ease of handling, security and transportation, the product should weigh no more than 25 kg. ✓ A large portion of the product weight is anticipated to come from the product frame and electrical motor.
8. Size	✓ To enable simple and secure handling and transportation, products should be small in size (less than 0.5 m in length, 0.5 m in breadth, and 0.5 m in height).
9. Maintenance	✓ Intervals between product maintenance should be at least a year. ✓ The reliability of the bearings and cutting blades should be used to determine the maintenance schedule. ✓ The product should be designed such that accessibility, availability, manufacturability and affordability are taken into consideration for the parts to be maintained.
10. Material	✓ Product materials should all fulfil hygienic conditions for food protection ✓ The least number of materials and the fewest variety of materials should be used to make the product.

	✓ Casting is an example of a procedure that shouldn't be used to make the product. ✓ As it is the available motor, the product should be powered by its 0.5 hp and 1400 rpm motor.
11. Storage	✓ The bearing shelf life, which is predicted to be 3 years, should determine the product shelf life. The product should be stored in its original packaging (SKF carrying shelf life). ✓ Product packaging dimensions should be standardized for shelves.
12. Aesthetics	✓ The colour of the product should be shiny, ideally metallic. ✓ The product should have a smooth surface and few to no edges. ✓ To make handling and transportation easier, the product should be packaged in a box package or a cylindrical package.
13. Ergonomics	✓ The product should be comfortable for the user to operate for 12 h. ✓ The product should not involve any smart technologies.
14. Reliability	✓ The bare minimum number of components should be in the product. ✓ Minimum joints should be present in the product.
15. Product testing	✓ To determine a product's usefulness, testing is recommended. ✓ The results of three tests should be averaged to determine the product's effective capacity. ✓ The testing vegetables, which are anticipated to be cucumber or carrot, should be used.
16. Disposal	✓ After the machine becomes obsolete, most of the components should be able to be used again.

A direct coupled circular disc to the motor and the connecting rod will be used to convert the rotational motion of the motor to the reciprocating motion of the blade. With the help of the guide on the machine frame, the blade will be able to move in a straight line during the slicing process. The first concept can be illustrated in Figure 1.

The second concept is a cutting disc which comprises a solid disc and blades that are mounted on the top surface of the disc. This disc will be mounted to the motor with the help of the connecting shaft that will couple with the motor on one side and attach disc on the other side. The motor will lie horizontally. Vegetables will be fed from the top back of the disc and collected on the lower front of the disc. Figure 2 shows the schematic diagram of the second concept.

In the third concept, the motor will be at the bottom of the machine and vertically oriented. A cylinder that is coupled with the motor through a web-like structure to the centre shaft will be coupled with the motor to rotate the cylinder. The slicing blades will be mounted on the circumference of the disc along the direction of the shaft. Vegetables will be fed on the circumference and collected through the center of the cylinder. The third concept is illustrated in Figure 3.

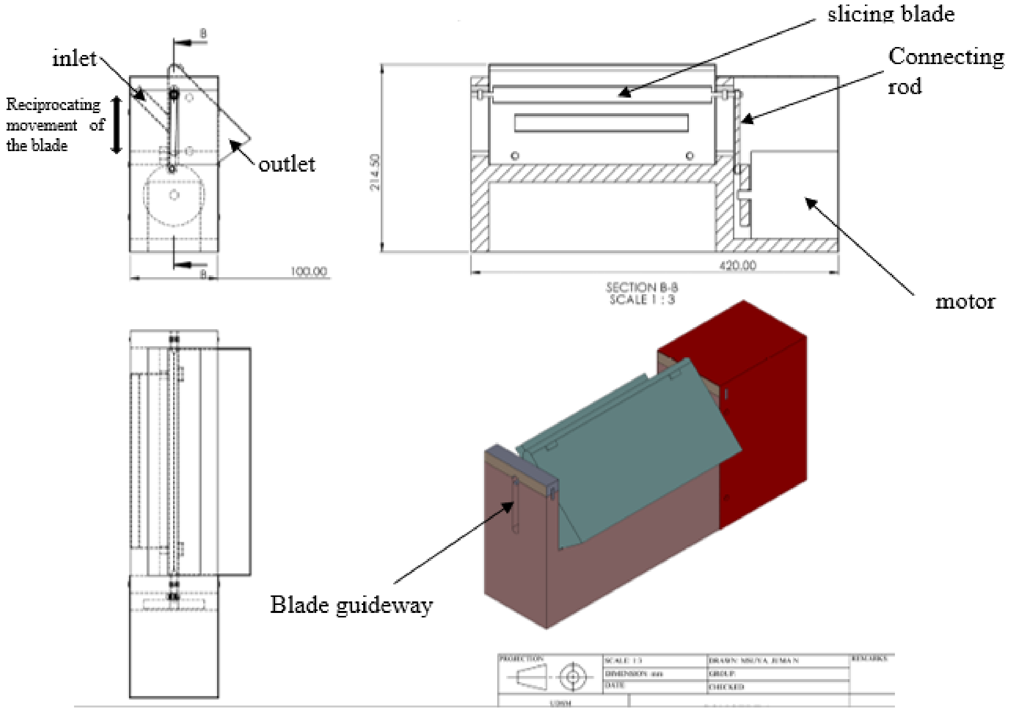


Figure 1: First concept of vegetable slicing machine.

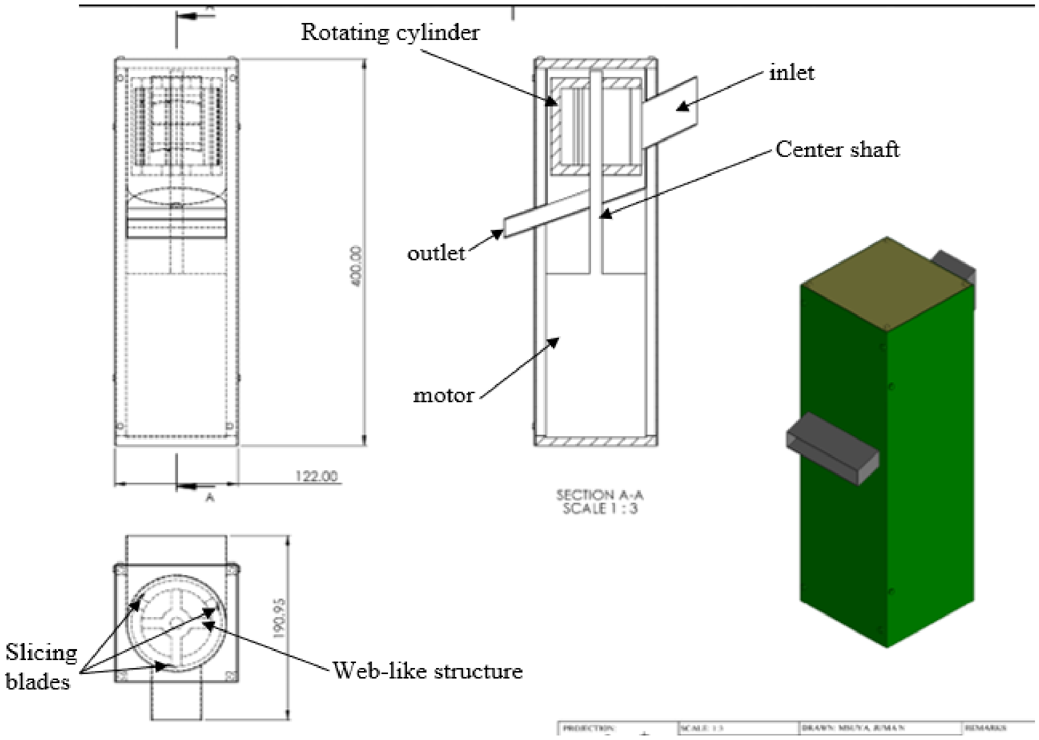


Figure 2: Second concept of the vegetable slicing machine.

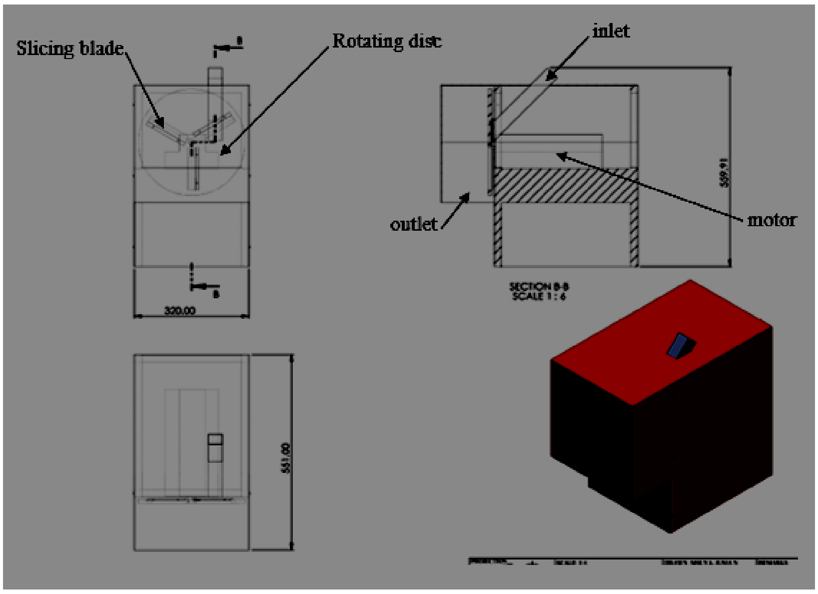


Figure 3: Third concept of vegetable slicing machine.

Concept Selection

The rating and weighting matrix method is used to select the best concept from the three discussed above. This selection considers the following selection criterion with their weights in brackets: performance (8), weight (7), size (6), cost of production (5), easy in manufacturing (4), reliability (3), ergonomics (2), aesthetics (1). Rating shows the competence of each product to the particular criteria. The assignment is done out of 5 as: 1 = very poor, 2 = poor, 3 = average, 4 = good, 5 = very good.
The best concept among the generated ones will be selected by considering the highest score. The scores (S_C) of the concept will be obtained by the product of the weight of the criteria (rate of importance, RI) and the rate of the respective concept (r_t), see Equation (1).

$$S_C = r_t \times NRI \qquad (1)$$

Normalized relative importance (NRI) is the relative importance of the particular criteria out of the sum of the relative importance of all the criteria selected.

$$NRI = \frac{RI}{\sum_{i=1}^{n} RI_i} \qquad (2)$$

From Table 2, CONCEPT 2 will be used for further design as it scored highest than the other two.

Table 2: Rating and weighting matrix.

	Concepts / Selection criteria			Concept 1		Concept 2		Concept 3	
S/N	**Criteria**	RI	NRI	r_t	S_C	r_t	S_C	r_t	S_C
1	Performance	8	0.222	3	0.666	5	1.11	5	1.11
2	Weight	7	0.194	4	0.776	4	0.776	4	0.776
3	Size	6	0.166	4	0.664	5	0.83	5	0.83

4	Cost of production	5	0.139	3	0.417	5	0.695	4	0.556
5	Easy in manufacturing	4	0.111	3	0.333	5	0.555	4	0.444
6	Reliability	3	0.083	3	0.249	4	0.332	4	0.332
7	Ergonomics	2	0.055	3	0.165	4	0.22	5	0.275
8	Aesthetics	1	0.027	3	0.081	4	0.108	4	0.108
Summation of the scores					**3.351**		**4.626**		**4.431**

Design analysis

Design analysis is carried out to determine the size of the functional sections for the efficient operation of this machine. The cutting disc, the shaft that connects the disc to the prime mover, the ball bearing that sits in the middle of the disc and the motor, and the electrical motor, are the functional components.

a) Slicing disc dimensions

According to Gladys *et al.* (2018), the amount of energy needed to cut the vegetable depends on the food's composition. Since carrot has the greatest cutting energy requirement of any vegetable (4.55 J), will be used in the analysis. Ishola & Adewole (2020) experimented and discovered that the slicing disc's cutting speed varies proportionally to the machine's slicing capacity and efficiency, i.e., the faster the speed, the higher the capacity and efficiency. The kinetic energy of the slicing disc should be more than or equal to the energy of the vegetable for effective slicing (carrot in this case). The design took advantage of the 0.5 hp, 1400 rpm available motor.

$$KE_d \geq 4.55J = \frac{1}{2}I\omega^2 \tag{3}$$

The angular speed of the drum is given by:

$$\omega = \frac{2\pi N}{60} = \frac{2\pi(1400)}{60} = 147 \text{ rad/s}$$

Whereby the moment of inertia of the drum is $I = mR^2$ and $m = \rho\pi R^2 t$. It is recommended that the slicing disc radius should at least be three times the diameter of the product to be sliced to allow the attachment of the slicing blade. This blade will provide a clear cut of the vegetable (Saravacos & Kostaropoulos, 2016). Also, Gladys *et al.* (2018) showed that the average diameter of the carrot is 31 mm which is ±30% deviation from what is found within Tanzania, which implies that the minimum radius of the slicing disc should be 93 mm. The 150 mm disc radius will be used to allow multiple vegetable feeding by increasing the slicing blade length. Due to the post processes to be done on the slicing disc, it is necessary to use hardwood. The hardwoods are the ones with a density of at least 500 kg/m^3 (Kayumba et al., 2016). With weight consideration and machine stability it is better to go for light hard wood. Thus, the slicing disc used wood material with density 500 kg/m^3, which using Equation (3) will give the thickness as 0.39 m.

$$4.55 \leq \frac{1}{2}\rho\pi R^4 t w^2, \tag{4}$$

Then, plugging the data as below:

$$4.55 \leq \frac{1}{2} \times 500 \times \pi \times (0.15)^4 \times t \times (147)^2$$

$t \geq 0.39$ m.

It is recommended that food processing equipment be oversized by 10-20% to avoid production problems as well as meet production peak (Saravacos & Kostaropoulos, 2016). However, this slicing disc has to undergo several processes which are chipping to fit the blades at an angle, mounting screws for blades attachment. In addition, maximizing its rigidity necessitates to increase the thickness. The minimum length of the screw for wood activities is 10 mm according to (EOTA, 2020). With such thickness, it implies that material of a lesser density (i.e., plastic) or motor of lesser speed can be used, however, with the limit of the available motor and post-processing of the disc, wood slicing disc is favourable.

b) *Motor rating*

The motor will be rated with power and its speed in rpm. Since the available motor is 0.5 hp and 1400 rpm, the following calculation is undertaken to check for its appropriateness.

Mass of the slicing disc is found as

$$m = \rho \pi R^2 t = 500 \times \pi \times 0.15^2 \times 0.01$$

$$m = 0.353 \text{ kg.}$$

Force required to rotate the mass is,

$$F = mw^2 R = 0.353 \times w^2 \times 0.15 = 0.053 w^2 \text{ N.}$$

$F = m\omega^2 R = 0.353 \times \omega^2 \times 0.15$The torque required is

$$T = FR = 0.053 w^2 \times 0.15 = 0.00795 w^2 \text{ Nm.}$$

Therefore, power of the motor is calculated as follows.

$$P = T \times w \Rightarrow 370 = 0.00795 w^2 \times w$$

The w = 35.97 rad/s for which the speed in rpm (N) is calculated as:

$$N = \frac{w \times 60}{2\pi} = \frac{35.97 \times 60}{2\pi} = 343.5 \text{ rpm.}$$

Since the required speed for slicing is less than the speed of the available motor (1400 rpm), then the motor will provide satisfactory performance. Further, with this high speed, the machine slicing capacity is increased and the damage to the vegetables is minimized. The efficiency of the machine was also taken into account by correlated disc speed and the feeding rate of the vegetable (Ishola & Adewole, 2020).

c) *Connecting shaft*

The slicing disc will be connected to the motor through the connecting shaft. The shaft will be designed against bending and torsional moment as it is subjected to the rotation motion of the motor and loads on its ends (slicing disc and fixed motor). The design of the shaft follows the ASME codes of steel shafts which state that for the shaft with keyway, maximum allowable shear stress (T_{all}) is 40 MPa, which can be computed from (4). $(\tau_{all}) = 40MPa$

$$T_{all} = \frac{16}{\pi d^3} \sqrt{(C_b M_b)^2 + (C_t T)^2} \quad (5)$$

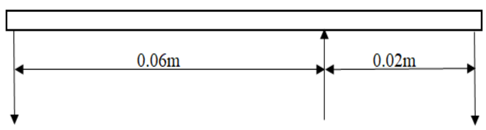
$$\tau_{all} = \frac{16}{\pi d^3} \sqrt[2]{(C_{bm} M_b)^2 + (C_t T)^2}$$

The torsional moment produced by the disc rotation is computed from the following.

$$T = mw^2 R^2 = 0.353 \times 147^2 \times 0.15^2$$

$$= 171.63 \text{ Nm.}$$

$T = m\omega^2 R^2 = 0.353 \times 147^2 \times 0.15^2$
Bending moments due to the forces exerted on the shaft by the motor, bearing and slicing disc are presented in Figure 4.



X Y 0.353(9.81) N

Figure 4: Forces exerted on the shaft

Bending moment about point Y is computed as, $0.353(9.81)(0.02) = 0.06X, \quad X = 1.154\,N$

$$0.0353 \times 9.81 \times 0.02 = 0.06X, \quad X = 1.154 \text{ N}.$$

For the equilibrium of the shaft, the force on Y should be $X + 0.353(9.81) = Y, \quad Y = 3.46\,N$

$$X + 0.353 \times 9.81 = Y, \quad Y = 3.46 \text{ N}.$$

$X + 0.353(9.81) = Y, \quad Y = 3.46\,N$

Bending moment of the shaft (M_b) is computed in the following.

$$M_b = 1.154 \times 0.06 = 0.06924 \text{ Nm}$$

$M_b = 1.154 \times 0.06,$

To ensure maximum strength of the shaft for competitive advantage, the factor for the torsional moment and bending moment will be taken to their extreme values.$M_b = 0.06924\,Nm$

Table 3:Torsional and bending moment factors from ASME design code.

$M_b = 1.154 \times 0.06, \quad M_b = 0.06924\,Nm$

Shaft state	Nature of the load applied	C_{bm}	C_t
For stationary shaft	Load gradually applied	1.0	1.0
	Load suddenly applied	1.5-2.0	1.5-2.0
For rotating shaft	Load gradually applied	1.5	1.0
	Load suddenly applied (minor shock)	1.5-2.0	1.0-1.5
	Load suddenly applied (heavy shock)	2.0-3.0	1.5-3.0

These are C_{bm} = 2 (the condition that the shaft is loaded suddenly), and C_t = 1.5 (the condition for minor shock). Then the diameter of the shaft will be computed as 3.2 mm shown below.

$$d \geq \sqrt[3]{\frac{16}{\pi T_{all}} \times \sqrt{(C_{bm} M_b)^2 + (C_t T)^2}} \qquad (6)$$

$$d \geq 3.2 \text{ mm}$$

The selected motor output shaft has a diameter of 12 mm, the connecting shaft should have a diameter higher than that to create a female-male junction. The connecting shaft will be used to connect the motor and the cutting blade. A 20mm diameter shaft is used, which is one ofthe usual shaft diameters. Since the shaft will be post-processed with drilling, threading, and welding operations, steel is a suitable material for the shaft. This is despite the big shaft diameter's implication that material of lower strength could be used.

d) Bearing

A deep groove ball bearing is used. From the SKF catalogue, the formula

$$C_{10} = F_d \left(\frac{60LN}{10^6} \right)^{1/a} \quad (7)$$

$C_{10} = F_d (\frac{60LN}{10^6})^{1/a}$, from which the constant (a) = 3 (for ball bearing), bore diameter of the bearing = 20 mm. Number of hours in operation (L) = 8760 h (equivalent to one year). The speed that the bearing will be subjected to (N) = 300 rpm. The force that will be exerted on the bearing (F_d) = Y = 6.932 N. Therefore, the C_{10} is calculated below.

$$C_{10} = 6.932 \times \left(\frac{60 \times 8760 \times 300}{10^6} \right)^{1/3} = 37.45 \text{ N}$$

From that SKF catalogue, a deep groove ball bearing of designation W61904-2RS1 with a 3.65 kN rated load will be used.

Manufacturing and testing

Manufacturing

Carpentry, electrical and machine workshop were used in the manufacturing of the machine as per Table 4. Machine workshops were the base workshop for manufacturing as most of the machine components are machine based.

Table 4: Manufacturing procedures

S/N	Machine part	Operation sequence
1.	Machine frame	
	i. Rear piece	• 450 mm × 410 mm of 20 mm thick wood was made by joining 100 mm wide sections of the material.
	ii. Identical two side pieces	• Two 100 mm wide, 20 mm thick pieces of wood were combined to create two 400 mm × 200 mm, 20 mm thick pieces • The material was removed that is 20 mm wide and 250 mm long along with 400 mm from each side piece's end
	iii. Front piece	• 450 mm × 410 mm of 10 mm thick wood was made by joining 100 mm broad, 20 mm thick pieces of wood. • Along 450 mm from the bottom end and 20 mm broad and 200mm long from both sides were removed • A hole of 37 mm in diameter, located 155 mm to the right and 278 mm from the bottom was drilled. • 305 mm from the bottom and 75 mm to the right, centering an elliptical hole with dimensions of 60 mm major radius and 30 mm minor radius were drilled.
	iv. Top piece	• 250 mm × 410 mm pieces of 20mm thickness were created by joining pieces of timber that are 100 mm broad and 20 mm thick.
	v. Slanted piece	• A 176 mm × 370 mm piece of 20 mm thickness was created by joining pieces of timber that are 100 mm wide and 20 mm thick.

	vi. Assembling the machine frame pieces	• the rear piece was positioned 450 mm vertically. • Two side pieces were raised such that 200 mm is vertical and the end from where the material was taken is on one of the sides. • Two side pieces were aligned such that the rear piece's ends are in touch with the ends of the removed material along 410 mm. • The two side pieces and the rear piece were assembled. • The top piece was aligned so that its 250 mm runs along the 250 mm of material that has been removed from the two side pieces and its 410 mm matches the 410 mm of the rear side piece. • The top side piece was joined. • The front side piece was aligned such that its 450 mm is vertical, material removed side is at the bottom between the two side pieces and in contact with the top side. • The front side piece was joined • The slanted piece was aligned such that the 370 mm side is horizontal and the 176 mm side is at 45^0 downward with vertical, between the two side pieces and in contact with the bottom • The slanted side was joined.
2	Slicing disc	• 100 mm wide and 10 mm thick pieces of timber were joined to obtain 350 mm × 350 mm piece of 10 mm thickness • 300 mm diameter disc from the piece above was cut. • Three 100 mm × 30 mm rectangles at 30 mm from the centre and 100mm side toward the circumference, equally spaced along the circumference were drilled. • 50 mm diameter at 5 mm depth at the disc centre were blind drilled. • 4 mm holes equally spaced at PCD 36 mm centered at the disc center were thoroughly drilled. • The right triangle of 10 mm length on the blind drilled surface of the disc was chipped, 2 mm right-angled side, slant side at 10^0 with horizontal to the second side which is perpendicular to the length, throughout the 100 mm length on one side of each rectangle. The chipping was made in the same direction.
3	Slicing blades	• Three pieces of 100 mm × 30 mm from 1.5 mm thickness stainless steel sheet were cut. • Three pieces 100 mm in length on one side were sharpened at an angle of 18^0. • Two 4 mm holes at 5 mm from the blunt side along 30 mm and 20 mm from each end along 300 mm length were thoroughly drilled.
	Connecting shaft	

	i. Plate	• A 50 mm diameter plate of 2 mm thickness from a stainless-steel sheet was cut. • 4 holes of 4 mm diameter equally spaced on PCD 36 mm centered at the plate center were thoroughly drilled.
	ii. Shaft	• 110 mm length of 20 mm diameter shaft were cut. • 12 mm diameter hole to a depth of 20 mm on one end was blindly drilled. • From the same end, threading of M4 × 1.5 on the circumference at 10 mm from the end was produced.
	iii. Connecting shaft	• Shaft and the plate concentrically and the shaft side that was not drilled in contact with the plate were aligned. • The shaft and the plate were joined.
5.	Feeding tube	• 300 mm long hollow cylinder with 60 mm diameter and 1 mm thickness made of stainless steel were cut. • 300 mm cylinder at the angle of 30^0 referenced to the length from one end were cut. • Two 20 mm × 10 mm plates of 1 mm thickness from stainless steel sheet were cut • A 4 mm diameter hole at the centre of each plate was drilled. • Plates with the cylinder at the extremities of the slant surface were joined.
6	Machine cover	
	i. Side and top cover	• 1314 mm × 402 mm sheet of 1 mm thickness made of stainless steel was cut. • Sheets into an n-shape were bent with 451 mm vertical sides and 412 mm horizontal tops. • Four holes on either vertical side 10 mm and 270 mm from the rear side and 50 mm and 350 mm from the top were drilled. • ellipse of major diameter 70 mm and minor diameter 60 mm located at 216 mm from the front and 75 mm from the right were drilled.
	ii. front cover	• 412 mm × 351 mm sheet of 1 mm thickness made of stainless steel was cut. • 4 holes of 4 mm diameter at 40 mm and 120 mm from the bottom and 10 mm from either side were drilled.
7	Assembling of the machine	• slicing blades were mounted to the slicing disc i.e., the blade lies on the chipped slanted side and the sharpened edge is directed to the drilled rectangle.
		• disc and the shaft were then bolted i.e., the shaft plate lies on the blind drilled hole.
		• a feeding tube was mounted to the machine frame (i.e., the slant side of the tube matched with the drilled ellipse hole on the front side, directed upward and between the front and rear side
		• covering the machine with sides and top cover (i.e.,

		the feeding tube pass through the ellipse of the top cover) then the front cover.

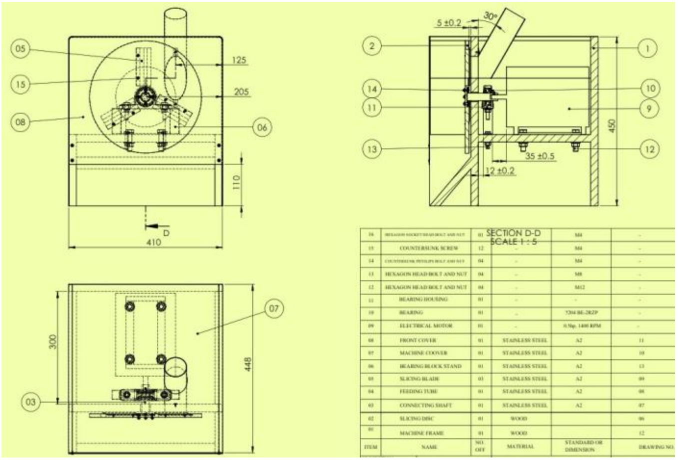


Figure 5: Engineering drawing of vegetable slicing machine.

Figure 5 shows the engineering drawing of the fully assembled vegetable-slicing machine.

Bills of Material

Table 5 shows a list of materials required for the manufacturing of the product and their respective costs.

Testing

After the completion of the product manufacturing, the product was tested by the stated parameter in the methodology. Six different amounts of the selected vegetable were prepared to start from 0.5 kg to 3 kg with 0.5 kg increments while other parameters were kept constant. This allows to get machine capacity, efficiency as well as a trend for the damaged vegetables. Table 6 shows the results obtained from the tests. The following Equations (5) – (6) were used to evaluate the results of the machine testing. The percentage weight of vegetable slices is presented as W_S, weight of sliced vegetables is W_{SV}, and total weight of the vegetables is $\sum W_V$. The percentage damaged vegetable is presented as W_{DV}.

$$W_S = \frac{W_{SV}}{\sum W_V} \times 100\% \qquad (8)$$

$$W_{DV} = 100\% - W_S \qquad (9)$$

Table 5: Bill of quantity

S/N	Description	Material	Size (mm)	The total weight (kg)	Rate (Tshs.)	QTY	Total cost (Tshs.)
1	Machine frame	Wood	450×410×20 400×180×20 400×180×20 410×300×20 450×410×20 370×176×20	8.528	6000/ (500×500)	4	24,000
2	Slicing blade	Stainless steel	30×100×1	0.024	1500/piece	3	4500
3	Connecting shaft	Stainless steel	ɸ20, length 90. ɸ50, thickness 2	1.54	20,000/piece	1	20,000
4	Machine cover	Stainless steel	450×410×1 450×450×1 450×450×1 410×400×1	5.7728	17,000/m^2	0.723	12,300
5	Feeding pipe	Stainless steel	ɸ60, length 300, thickness 1	0.5856	17,000/m^2	0.058	1,000
6	Motor	0.5hp, 1400RPM		7	110,000	1	110,000
7	Bearing and its block	7204 BE-2RZP	ɸ47, length 14	0.5	10,000/piece	1	10,000
8	M12 bolt and nut	Mild steel	45 mm	0.324	500/piece	6	3000
9	M4 bolt and nut	Stainless steel	25 mm	0.0156	200/piece	5	1000
10	M4 screw	Stainless steel	24 mm	0.01872	200/piece	6	1200
11	Nails	Mild steel	50 mm	1	5000/kg	1	5000
Total				**25.31**			**192,000**

Table 6: Test results

S/N	Speed (RPM)	Total amount (kg)	Time (sec)	The percentage amount of slices (%)	The percentage amount of damages (%)
1	1400	0.5	55	77	23
2	1400	1	122	81	19
3	1400	1.5	169	87	13
4	1400	2	226	90	10
5	1400	2.5	296	92	8
6	1400	3	352	91	9

The results in Table 6, showed that the average machine capacity is 30 kg/hr.

with 86% of the sliced vegetables with the percentages of slices increasing as percentage damage decreases.

Conclusion

The design, manufacturing and testing of vegetable slicing machine was reported following the Pugh's method. All procedures were outlined and explained. The machine capacity was to slice 30 kg/h at an efficiency of 86%. During testing, the machine capacity will vary between person and person due to different feeding delays as the product involves manual feeding of the vegetables. The modified machine could be advanced to have an automated feeding system and if possible, reduction of size.

Implication to practice

Generally, the mechanization of the process will increase its efficiency of the process, lower the safety risk, rise the hygiene level and minimize the losses. Specifically, because the quality (i.e., uniform size of the slices) of the process will be improved, the price of the service will rise, and increasing process efficiency will result in an increase in financial benefit to the vendor. The entire society would benefit from improved hygiene because it will help to ensure society's health and safety. The equipment will comparatively reduce the safety risk, which will be advantageous to the vendor because there will be fewer injuries sustained by the vendor. Maximizing the output yield will increase the vendor's profit because they will receive more of the output, and there will also be an increase in revenue.

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REFERENCES

Asonye, G.U., Asoegwu, S.N., Maduako, J.C. and Madubuike, C.J. (2018) 'Energy requirements for cutting of selected vegetables: A review', *Agricultural Engineering International: CIGR Journal*, **20**(4): 139–148.

Bello, R.S., Onyeanula, P.E. and Nnaamah, A. (2017) 'Design and performance evaluation of a small-scale multi-crop chipper', *Proceedings of the 18th International Conference of the Nigeria Institution of Agricultural Engineers (NIAE)*, pp. 93–99.

Eliçin, A.K. and Pekitkan, F.G. (2019) 'Effect of Various Knife Type, Cutting Angle and Speed on Cutting Force and Energy of Grape Cane', *European Journal of Science and Technology*, **15**: 519–525. https://doi.org/10.31590/ejosat.532914.

EOTA (2020) 'Screws and Threaded Rods for Use in Timber', (February 2019), pp. 1–28.

Hoque, M.A. and Saha, K.K. (2017) 'Design and development of a manual potato cum sweet potato slicer', *Journal of Science, Technology and Environment Informatics*, **5**(2): 395–401. https://doi.org/10.18801/jstei.050217.42

Ikpoza, E., Usiobaifo, E.J. and Erhunmwun, I.D. (2021) 'Design and Fabrication of a Manually Operated Vegetable Leaf Slicing Machine', *Journal of Applied Sciences and Environmental Management*, **25**(2): 195–198. https://doi.org/10.4314/jasem.v25i2.9.

Ishola, T.A. and Adewole, L. (2020) 'Development and Performance Evaluation of an Okra Slicer', *Arid Zone Journal of Engineering, Technology and Environment*, **16**(2):

269–278. Retrieved from https://www.azojete.com.ng/index.php/azojete/article/view/208

Kahandage, P.D., Wathsala, R.H.G.R., Dharmasena, D.A.N. (2013) 'Designing, Development and Performance Evaluation of a Manualy Operated Leafy Vegetable Slicing Machine for Domestic Use,' *Annual Research Symposium 2013*, 1–2.

Kayumba, I., Iddi, S., Augustino, S. and Makonda, F.B.S. (2016) 'Variation of basic density and fibre length in *Lonchocarpus capassa* (Rolfe) wood from Kilosa District, Tanzania', *Tanzania Journal of Forestry and Nature Conservation* **86**(1): 12–21.

Krantidip, R.P., Pravin, D.U., Pritam, D.B., Kaustubh, B.G., Rushikesh, B.J. and Aniket, A.P. (2020) 'Development of Fruit and Vegetable Slicing Machine', *International Research Journal of Engineering and Technology (IRJET)*, **7**(3): 1399-1404.

NPHMS. (2018) 'National Post-Yield Management Strategy-NPHMS'.

Salaudeen, K.O. and Fidelis, A.E. (2017) 'Design and Development of a Tomato Slicing Machine', *International Journal of Engineering & Technology*, **13**(2): pp. 197–208.

Saravacos, G. and Kostaropoulos, A.E. (2016) 'Mechanical processing equipment', in *Food Engineering Series*, 149–232. https://doi.org/10.1007/978-3-319-25020-5_4.

Sonawane, S.P., Sharma, G.P. and Pandya, A.C. (2011) 'Design and development of power operated banana slicer for small scale food processing industries', *Research in Agricultural Engineering*, **57**(4): 144–152.

Asonye, G. U., Asoegwu, S. N., Maduako, J. N., & N.madubuike, C. (2018). Energy requirements for cutting of selected vegetables: A review. *Agricultural Engineering International: CIGR Journal*, **20**(4): 139–148.

Bello, R. S., Onyeanula, P. E., & Nnaamah, A. (2017). *Design and performance evaluation of a small-scale multi-crop chipper*.

Eliçin, A. K., & Pekitkan, F. G. (2019). *Effect of Various Knife Type , Cutting Angle and Speed on Cutting Force and Energy of Grape Cane*. **15**: 519–525. https://doi.org/10.31590/ejosat.532914

EOTA. (2020). *Screws and Threaded Rods for Use in Timber*. *February 2019*, 1–28.

Hoque, M. A., & Saha, K. K. (2017). *Design and development of a manual potato cum sweet potato slicer*. **5**(2): 395–401.

Ikpoza, E., Usiobaifo, E. J., & Erhunmwun, I. D. (2021). Design and Fabrication of a Manually Operated Vegetable Leaf Slicing Machine. *Journal of Applied Sciences and Environmental Management*, **25**(2): 195–198. https://doi.org/10.4314/jasem.v25i2.9

Ishola, T. A., & Adewole, L. (2020). *Development and Performance Evaluation of an Okra Slicer*. **16:** 269–278.

Kayumba, I., Iddi, S., Augustino, S., & Makonda, F. B. . (2016). *Variation of basic density and fibre length in Lonchocarpus capassa (Rolfe) wood from Kilosa District , Tanzania*. *86*(1).

Krantidip R. Pawar, Pravin D. Ukey, Pritam D. Bhosale, Kaustubh B. Ghorpade, Rushikesh B. Jadhav, A. A. P. (2020). *Development of Fruit and Vegetable Slicing Machine*.

NPHMS. (2018). *National Post-Yield Management Strategy-NPHMS*.

P.D. Kahandage, R.H.G.R. Wathsala, D. A. N. D. (2017). *Design, Development and Performance Evaluation Operated Leafy Vegetable Slicing Machine for Domestic Use*. 1–2.

Salaudeen, K. oladimeji, & Fidelis, A. (2017). Design and Development of a tomato Slicing Machine. *International Journal of Engineering & Technology*, **13**(2): 197–208.

Saravacos, G., & Kostaropoulos, A. E. (2016). Mechanical processing equipment. In *Food Engineering Series* (pp. 149–232). https://doi.org/10.1007/978-3-319-25020-5_4

Sonawane, S. P., Sharma, G. P., & Pandya,

A. C. (2011). *Design and development of power operated banana slicer for small scale food processing industries*. **57**(4): 144–152.