Vol. 14, No. 3 (2025): 920 - 932 http://dx.doi.org/10.23960/jtep-l.v14i3.920-932

JURNAL TEKNIK PERTANIAN LAMPUNG

ISSN 2302-559X (print) / 2549-0818 (online)
Journal homepage : https://jurnal.fp.unila.ac.id/index.php/JTP

Design and Technical Evaluation of a Tempeh Slicer Using Stainless Steel Rotating Disc with Three Curved Blades

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Article History:

Received : 09 February 2025
Revised : 06 Maret 2025
Accepted : 17 Maret 2025

Keywords:

Curved rotary knife,
Low power consumption,
Slicer,
Slicing machine,
Tapioca tempeh chip.

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ABSTRACT

A tempeh chips slicing machine has been developed. This machine was developed based from the results of the previous research. The main slicing component is a stainless steel rotating disc equipped with three curved knives. With this knives geometry arrangement, slicing can be done at high speed. High speed is possible due to the absence of reciprocating motion and due to smooth cutting strokes. A variable speed 550W brush-less direct current motor was employed to power the slicing mechanism. The machine was tested at motor speed of 500, 600, 700, 800 and 900 rpm. Across all speeds, the machine consistently produced chips of 1 mm thickness that is in compliance with industrial requirement. The machine produced up to 96% of intact slices, with slicing capacity of 53 kg/h (692 slices/min) and a very low electric power consumption ranged from 23 W (at 500 rpm) to 60 W (at 900 rpm). The machine can slice several chip solid materials with good results, therefore it has the potential to be developed into a multi-purpose chip slicer.

1. INTRODUCTION

Tempeh is a food ingredient that is widely known in Indonesia (Shurtleff & Aoyagi, 2022). Tempeh is a food made by mixing cooked soybeans with a culture known as "tempeh yeast". Tempeh can be served as a side dish or made into further processed foods (Catherine *et al*., 2022), one of which is chips (Setiawan *et al*., 2024). Tempeh chips are made from tempeh that is sliced into thin sheets and then fried. Tempeh chips are made from pure tempeh and some are made from a mixture of fermented soybeans and flour. The flour used is generally tapioca. The addition of tapioca produces crispier chips so that consumers like them.

The making of tempeh chips begins with making round-shaped tempeh bars. The ingredients used are fermented soybeans mixed with tapioca flour (Nifah & Astuti, 2015). After fermentation for about 24-36 h, which is the optimum period for mold growth (Wahyudi, 2018), the bars are then thinly sliced. The slices are then fried, air cooled and put into packaging. Slices that are well-shaped and have the right thickness will produce crispy chips and an attractive appearance. Slicing using a machine makes it easier to obtain the right slices. Currently, there are quite a lot of slicing machines for making tempeh chips on the market. However, most still use a slow cutting method, namely by sliding the tempeh back and forth. This is because most of the slicing knife designs are in the form of disc knives, namely discs with the outer edges are sharpened. The slicing method that requires back and forth movements makes it difficult to increase its work capacity.

Basically, the design of a disc-type slicer (also called a reciprocating type or sliding type) consists of a rotating disc that is sharpened on the outer circumference. The slicing method is by sliding the tempeh back and forth with the tip touching the rotating disc. The disc material can be from a rotary saw blade (Putro, 2006; Garside & Sudjatmiko, 2016), stainless steel plate (Rofarsyam, 2012; Porawati & Kurniawan, 2021; Hariri *et al*., 2022), steel plate (Pujiono & Hindryanto, 2017), and from motorcycle brake discs (Agtriandy *et al*., 2022; Gibroni *et al*., 2024). Discs made from stainless steel are good choice because they produce less friction, easy to clean and more suitable for food processing.

In addition to slicing using a disc knife, tempeh slicing was also tried using a straight rotary knife. This type does not require back and forth movement so that cutting is faster. The straight rotary knife design is highly suitable for cutting most chip materials like cassava (Fahrizal *et al*., 2024), taro (Wardianto *et al*., 2023), or plantain (Dharmawan *et al*., 2022). However, it is not suitable for cutting tempeh. Slicing tempeh using this design results in a high level of damage. The resulting damaged slices are up to 15.3% (Luthfi *et al*., 2016), 25.97% (Handoko *et al*., 2018), and some even reach 71% (Yahya *et al*., 2022). The worst level of damage is 98% or almost all slices are damaged (Utomo & Nurlaila, 2021).

In addition, "spiral" curved blade designs have also been developed (Istiadi *et al*., 2022; Tasliman *et al*., 2024). In these designs, the curved shape of the sharp part of the blades has the potential to reduce the percentage of slice damage. However, in these designs, only one blade can be installed on the disc. This construction results in shaky rotation at high speeds.

In the study by Tasliman (2023) a slicing machine with satisfactory performance has been made. In this design, three curved blades were installed on a motorcycle brake disc. In tempeh tapioca slicing tests, the machine achieved a 96.5% success rate of fried slices, with an average thickness of 0.85 mm and a power consumption of 29.7 W. The use of three blades resulted in stability at high speeds. Although the concept and performance were good, the design of the blade system was poor in terms of construction. The exposed blade design posed a significant safety risk to the user. Additionally, the carbon steel retaining plate was unhygienic for food processing and exhibited insufficient structural integrity. Therefore, a redesigned system is required to enhance both safety and food-grade performance. The purpose of this study was to create a new design for a tempeh tapioca slicer using a stainless steel rotating disc in order to obtain a better performance. The new design, incorporating stainless steel components and modified geometry, was aimed to become safer, easier to operate and maintain, more reliable in producing proper slices, and more suitable for food processing.

2. MATERIALS AND METHODS

The design development was carried out at the "Bengkel Mesin Bedadung Mandiri" Workshop, Jember. Laser cutting was carried out at the Agricultural Engineering Study Program of the Jember State Polytechnic. At the modeling stage, a computer was used with the Geogebra (https://www.geogebra.org/), FreeCAD (https://www.freecad.org/), and Blender (https://www.blender.org/) were installed. The Geogebra was used to create a mathematical knife curve design. The FreeCAD was used to create model drawings, while the Blender was used for rendering 3-dimensional (3D) models. The materials used at the machine manufacturing stage were angle iron, stainless steel plates, and others, which can be seen in Table 1. The components were classified as raw (RM) and prefabricated (PF) materials.

Table 1. List of main machine components

Categories	No.	Parts	Qty	RM/PF	Material / Specification
Functional parts	1	Disc	1	RM	SS (stainless steel) plate 4 mm
	2	Knives	3	RM	HCS (high carbon steel) plate 2 mm
	3	Inlet	1	RM	PVC (polyvinyl chloride) pipe 2 in ; SS 0.4 mm
	4	Outlet	1	RM	SS 0.4 mm
Drive parts	5	Electric Motor	1	PF	BLDC "motor servo" JK513D, 550 W
	6	Small pulley	1	PF	A1, 3 in, cast aluminum
	7	V-Belt	1	PF	M50
	8	Big pulley	1	PF	A1, 11.5 in, cast aluminum
	9	Shaft	1	RM	LCS (low carbon steel) rod, D 0.75 in
	10	Bearings	2	PF	Pillow block, P204
Frame	11	Main body	1	RM	Angle iron 4x4 cm

The tools used for cutting were angle grinders, a cut off machine, a plasma cutter, and a laser cutter. The joining and assembly of parts used SMAW (Shielded Metal Arc Welding), MIG (Metal Inert Gas) welding, and nut-bolt connections. The main stages in the implementation of this research consisted of designing, manufacturing and assembling the machine, followed by functional testing and performance testing.

2.1. General Design Concept

This machine consists of four main parts, namely functional components, drive components, machine frame and complementary components. Functional components are the parts of the machine that are directly related to the processing of materials. Functional components consist of a tempeh inlet path, a rotating disc equipped with three curved knives and a funnel for discharging the sliced results. From the functional components, the most important is the design of the rotating disc as the slicing component. The driving components are the parts of the machine that are responsible for supplying power so that the machine can function. The driving components consisted of an electric motor, motor pulley, V-belt, slicing shaft pulley, slicing shaft, and bearings. The frame or structural component is the part of the machine that is responsible for forming the machine into a complete and integrated structure. The frame is responsible for supporting other machine parts and ensuring that each component occupies the correct position. Complementary components are components that help the function of the machine, secure the use of the machine, or add aesthetic value to the machine. The most important complementary components were cables and switches for electrical connections. Some components were purchased in the form of raw materials (RM) and then made in the workshop, some were components that are purchased prefabricated (PF). Details of materials and components are given in Table 1.

The components in prefabricated form for making this machine consisted of an electric motor and its accessories, pulleys, V-belts, bearings (pillow blocks) and nuts and bolts. Other components were components that were purchased as raw materials (RM). The shaft was prefabricated but must be cut into the appropriate length.

The electric motor used in this machine is a “Jack” sewing machine BLDC (brush-less direct current) motor, JK-513D series with a rated power of 550 W. The bearing for the slicing disc shaft are P-type pillow blocks. This machine uses a 0.75 inches shaft, so 204 size pillow blocks are used. There are 2 pulleys, namely the slicing shaft pulley and the motor pulley. The motor pulley is included with the purchase of the motor and has a diameter of 7.5 cm. The cutting shaft pulley is made of aluminum with a diameter of 29 cm. The V-belt used in this machine is M50. This machine uses an M-type belt because the power transmitted is quite small.

2.2. Design of the Slicing Disc and Blades

The most important component in determining the performance of the slicing machine is the slicing disc and its blades. For this machine, the first factor considered in the design of the disc is its material. Meanwhile, the main factors considered in the design of the blades are its shape and arrangement, although the material is also an important consideration.

The shape of the sharp edge of the knives are curved to produce smooth slicing and does not damage the slices at high speed. When the curved sharp edges of the knives slice the tempeh, the contact of the sharp side does not occur abruptly along the sharp line. Thus the magnitude of the shock that occurs can be reduced. That way slicing can be done at high speed.

2.2.1. Dimensional consideration

The slicing disc is a circular plate equipped with three curved blades. The blade position was inherited from a previous design (Tasliman, 2023) because it gave good slicing results. The following explanation is based on Figure 1. The inner trajectory (r_1) was set to 10.5 cm, consistent with the previous design. The outer trajectory (r_2) is set 6 cm beyond r_1, enabling the disc to slice tempeh bars with a 4 cm diameter. The disc diameter is determined by adding 1 cm radius to give it a sufficient structural strength, resulted in a 35 cm diameter.

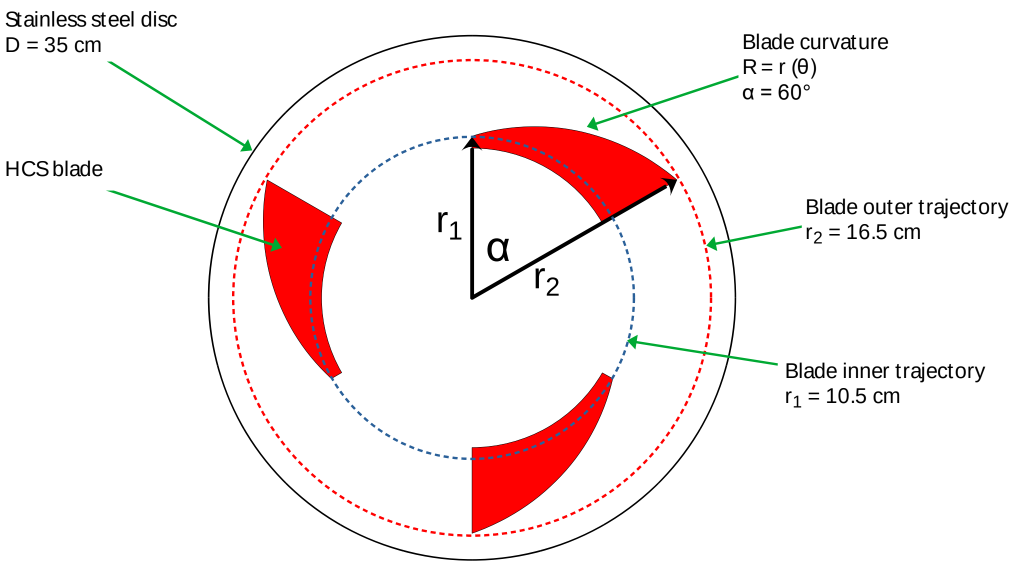

Figure 1. Reference image for the rotating disc design

The blade curvature was engineered to provide smooth contact during slicing. Essentially, the design replicated an inclined knife approach; however, due to the rotational motion, the cutting edge was made curved. The curvature was made mathematically using the equation

$$R(\theta) = r_1 + \frac{\theta}{\alpha}(r_2 - r_1) \tag{1}$$

where $R(\theta)$ is blade curvature radius at the angle of θ, r_1 is blade inner trajectory = 10.5 cm, r_2 is blade outer trajectory = 16.5 cm, α is blade curvature angle = 60°, and θ is angle value at a specific point, $0 \leq \theta \leq \alpha$

At the initial point ($\theta = 0$), $R(\theta) = r_1$. At the end point ($\theta = \alpha$), $R(\theta) = r_2$. The blade curvature angle (α) was set to 60°, same with the previous design.

2.2.2. Material selection

The knives were made from High Carbon Steel (HCS) plate from an ex band-saw because it can be sharpened sharply and is quite rust-resistant. A sharp blade is very important to reduce cutting force and reduce the risk of damage to the slices. In terms of food cutting safety, the use of HCS material is also quite good because even though it is not included in the stainless category, it is quite resistant to rust. With cleaning and drying with a cloth, this type of knife will not rust for days. With routine use every day, it is practical that knives made from this material will not have time to rust. In terms of availability, ex band saw plate material is quite easy to obtain from online stores.

The rotating disc is made using stainless steel because of its three advantages, namely a smoother surface, no rust, and easy to clean. With a smooth surface, it is expected to reduce friction when the plate has to rotate while its surface continues to rub against the surface of the tempeh being sliced. The rust-free and easy-to-clean material is intended to ensure that the sliced results are cleaner and healthier and easy to maintain. Through the disc plate, three narrow, elongated slots were made with a shape that follows the curvature of the knife as the passages for the slices to pass through when used for slicing.

In this design, the number of blades is made three with a distance of 120°. There are two advantages to this. First, by using three blades, each rotation of the disc will produce three cuts. Thus, the work capacity can be higher. Second, the placement of three blades symmetrically produces stable rotation at high speed (Tasliman, 2023). The model of the three blades attached to the rotating disc was presented in Figure 2 in the Section 2.4. The picture also shows the shape of the elongated curved passages through the slicing disc that follow the curvature of the blades.

2.3. Motor and Power Transmission Selection

2.3.1. Motor selection

In making this design, a sewing machine BLDC "servo" motor is used because of its advantages, namely low power consumption, variable speed, low noise, and low vibration. In the study by Tasliman (2023), it was found that the use of a "servo" motor requires much lower electric power input than an induction motor. With low power consumption, the machine can be used by MSMEs (Micro, Small and Medium Enterprises) which only have a 450 W power connection. The availability of speed setting buttons makes adjustments to obtain optimal speed easy, practical and inexpensive. The low noise and vibration of the motor will make the use of the machine more comfortable for the operator and those around. Table 2 shows a comparison between the use of a 0.5 HP (horsepower) 1400 rpm (revolution per minute) induction motor with a BLDC "servo" motor when used in slicing tapioca tempeh.

Table 2. Comparison of power usage using two types of motors

Motor type	No-load power consumption (W)	Cutting power consumption (W)	Actual power consumption (W)	Efficiency (%)
Induction	214.35	248.65	32.24	14.15
BLDC "servo"	14.58	29.71	15.13	50.9

Source: processed from (Tasliman, 2023)

2.3.2. V-Belt

This machine uses an M-type V-belt as is commonly used in household washing machines. This choice was made because the power transmitted is quite small. The M-type V-belt measuring 10 mm is more tender than the A-type measuring 12.5 mm. Therefore, the power required to bend and straighten the M-type belt during rotation is smaller. Thus, the power loss caused by continuous deformation when the belt rotates will be small. The disadvantage of using an M-type V-belt is that it is more difficult to obtain on the market than the A-type and can only be used to transmit small power.

2.3.3. Pulleys and shaft

The lowest speed of the motor (500 rpm) was still too high for slicing using this design. The motor included a 7.5 cm diameter cast aluminum pulley. To reduce the motor's speed to a suitable slicing speed, a second pulley with a larger diameter was needed. A 29 cm diameter precast aluminum pulley, readily available in market and approximating the slicing disc size, was selected. The machine's design prioritized simplicity, therefore it was built with only this single-stage transmission. With this arrangement, a speed reduction of 3.9:1 was achieved.

In the previous study using the same three curved blade concept (Tasliman, 2023), the electric power consumption was approximately 30 W at slicing disc speed 110 rpm (≈11.52 rad/s). The torque transmitted through the shaft, T = 30W/11.52 rad/s ≈ 2.60 N.m. The ultimate stress value for common structural steel is 340-830 MPa (Gere & Timoshenko, 1991). As the tensile strength of the shaft material was unknown, it is always safe to take the lowest value. The minimum diameter of the shaft was estimated using the following formula (Klebanov *et al*., 2008).

$$d \approx (5 \text{ to } 6)\sqrt[3]{\frac{T}{S_u}} \tag{2}$$

$$d = 6\sqrt[3]{\frac{2600}{340}} = 11.82 \text{ mm} \tag{3}$$

where d is shaft diameter (mm), T is transmitted torque (N.mm), and S_u is tensile strength of the shaft material (MPa).

The calculated 12 mm minimum shaft diameter was deemed inadequate due to potential bending. A 19 mm diameter shaft was selected for practical reasons, including market availability and to provide sufficient stiffness to prevent bending under load.

2.4. Machine Assembly and Performance Testing

From the design concept, a model was then created using FreeCAD. The results of the 3D model rendered using the Blender are shown in Figure 2. The main body component was made by cutting 4x4 angle iron using a cut off machine and joining them according to the drawing. For making the disc, cutting was done using a laser cutter because the curved and narrow shape of the slots were quite difficult to cut in other ways. The manufacturing steps were first to make a model using FreeCAD, then export it to DXF (drawing exchange format) so that it can be read by a laser cutting machine. The stainless steel plate material for the disc was cut into a square shape using a plasma cutter and then transported to the cutting location. The knives geometry was drawn using Geogebra, then exported to PNG (portable network graphics) format and printed on paper. The paper was then cut and glued to the plate which was then cut using an angle grinder. The curved edges were sharpened on one side only, using a grinder, whetstone and file. Other components were also prepared according to the drawing. For prefabricated components, just bought them from some store, either locally or online.

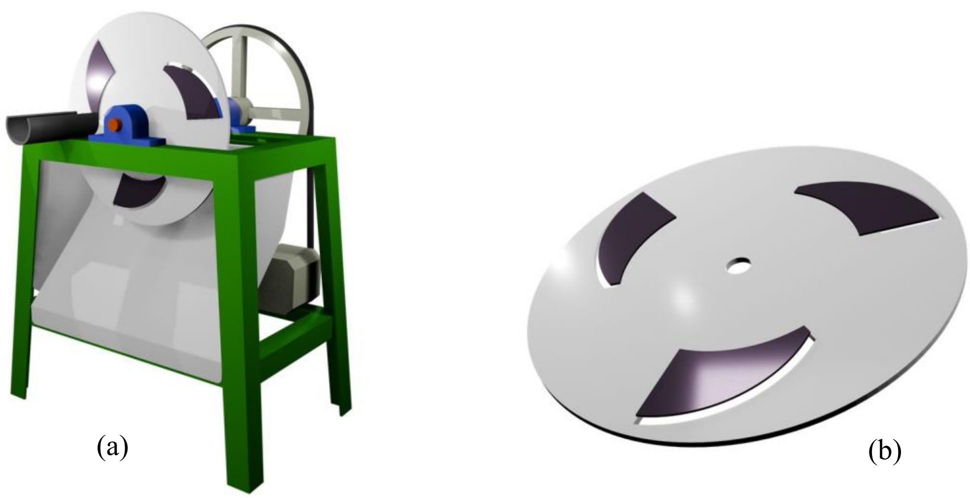

Figure 2. (a) 3D model of the design, (b) 3D model of the slicing disc and its blades

After the components were ready, both in the form of manufactured onsite or prefabricated, then each was assembled with each other in their respective places. The installation of the knives to the disc used 6 mm bolts. After that, a functional test was carried out. After the machine was functioning properly, then painting was carried out.

After the machine was deemed ready and functioning properly, a performance test stage was then carried out. The performance test was carried out by trying out the machine for slicing tapioca tempeh bars. The chips material was in the form of round shaped tempeh bars with a diameter of 4 cm and a length of about 45 cm, made by the research team with direction and supervision from the producer of tapioca tempeh chips "Bu Min".

In the performance test, measurements of work capacity, work quality and power consumption were carried out at motor speeds of 500, 600, 700, 800 and 900 rpm. The slicing method is by manual pushing using hands. Speed settings can be done easily because the motor used is equipped with a speed control button. All measurements (electrical power input of the motor, motor rpm, and slicing disc rpm) were carried out using a data logger except for the weighing that using a digital scale. All measurement results with a data logger were recorded in CSV (comma-separated value) format and stored on a micro-SD. After being copied to a computer, the data was then further processed using LibreOffice Calc (https://www.libreoffice.org/).

The slicing capacity was calculated by weighing the tempeh, measuring the slicing time and then converting it into kg/h units. The start and end times of slicing can be known by looking at the changes in the power reading value in the data logger. Before slicing, the power value is constant. When slicing, the power will suddenly increase, then remain constant for some time. When the power suddenly drops again, it means that slicing is completed. The slicing time was calculated from the recorded time when the power starts to increase until the power starts to decrease again. This reading method is more accurate than using a stopwatch. The slicing capacity conversion formula is:

$$C_s = \frac{W}{t} \times 3.6 \tag{4}$$

where C_s is slicing capacity (kg/h), W is weight of sliced tempeh (g), and t is slicing time (s).

The slicing quality was measured by the thickness of the slices and the percentage of the weight of the intact slices. Because visually it could be seen that the thickness of the slices is uniform, the thickness measurement was carried out by measuring the length of the sliced material and then dividing the result by the number of slices to obtain the average thickness. This method was chosen because the tempeh slices are soft so it was difficult to measure their thickness one by one with a caliper.

In power measurement, the electric power input to the electric motor was measured using a wattmeter-logger. Power measurements were taken when the machine is not cutting and when the machine is cutting. The difference in electric power consumption is the actual power requirement for the slicing job.

$$P_A = P_W - P_i \tag{5}$$

where: P_A is actual power consumption required for tempeh cutting (W), P_W is power consumption of electric motor during cutting (W), and P_i is power consumption of electric motor when in idle (W)

3. RESULTS AND DISCUSSION

3.1. The Manufactured Machine and Functional Test

In this research, a machine was successfully manufactured as shown in Figure 3a and 3b. Improvements in the disc design have resulted in a machine design that is safer and simpler in construction than the previous generation of designs (Figure 3c). In the previous design, the sharp parts of the blades were exposed, posing a safety hazard to the operator. The new design was safer because the sharp parts were contained by the disc.

Functional test by trying the machine to slice tempeh showed that the machine has functioned well. In addition to tempeh, the machine was also tested on several other chip materials, namely cassava, sweet potato, taro, and banana. From the experiment, it was observed that the machine can be used to cut several types of chip materials effectively. Thus, it had the potential to become a multi-purpose slicing machine for various chips. For this reason, it is necessary to conduct research on the performance of the machine for slicing other chip materials.

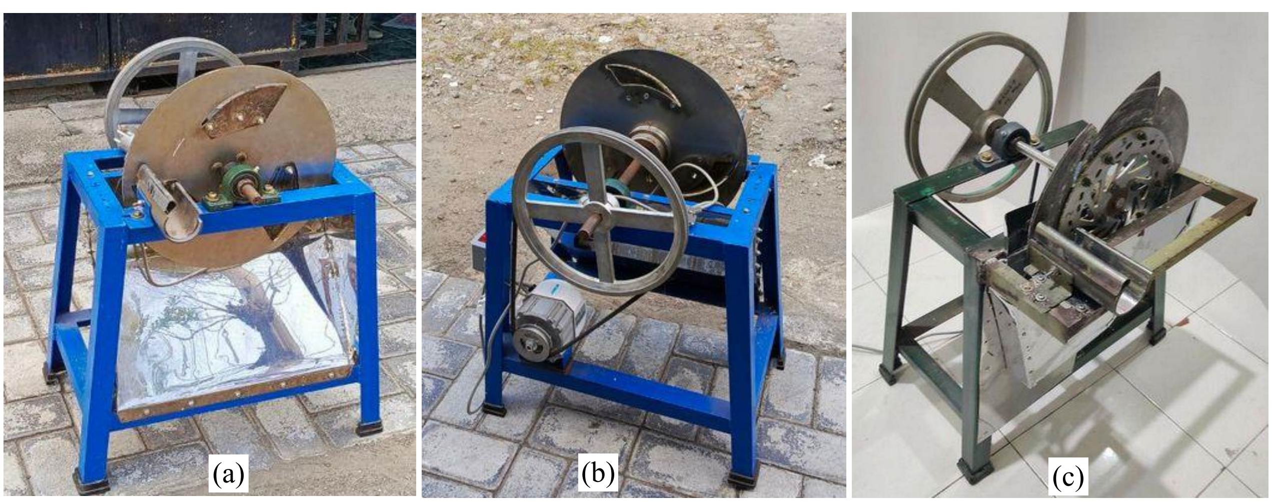

Figure 3. Newly designed (a and b), and first generation curved blade slicing machine (Tasliman, 2023)

3.2. Performance Test Results

Initially the test was planned at three speeds only: 500, 600, and 700 rpm. But because the results were all good, a second test at 700, 800, and 900 rpm was conducted to discover the results at higher speeds. The second test was conducted a few days after the first one. A set of new tempeh bars were prepared for it. To differentiate between the two materials, the name “A” and “B” were assigned to the first set and the second one respectively.

3.2.1. Speed measurement

Table 3 shows the actual speed of the motor and the slicing disc. The data presented in Table 3 highlights two significant aspects of the system's performance. Firstly, the BLDC motor exhibits robust speed stability, effectively maintaining the target speed despite load variations. This confirms its inherent speed regulation capabilities. Secondly, the near-constant speed ratio across all test conditions underscores the effectiveness of the M-type V-belt and A-size pulley combination in transmitting power with minimal loss due to slippage. This indicates a highly efficient power transmission system.

Table 3. Actual motor and slicing disc speed

Test	Test set	Setup speed (rpm)	Actual motor speed (rpm)	Disc speed (rpm)	Ratio
1			501.18	128.67	3.90
2		500	502.53	128.64	3.91
3			500.86	128.58	3.90
4			601.28	154.41	3.89
5	I	600	601.06	154.51	3.89
6			600.16	154.50	3.88
7			701.12	180.25	3.89
8		700	703.30	180.06	3.91
9			699.57	180.27	3.88
10			701.37	180.44	3.89
11		700	702.50	180.25	3.90
12			701.38	180.34	3.89
13			801.36	206.04	3.89
14	II	800	802.95	206.07	3.90
15			801.11	206.00	3.89
16			902.40	231.59	3.9
17		900	902.39	231.63	3.9
18			901.99	231.66	3.89

3.2.2. Slicing capacity

Figure 4 shows the average calculation results of the measurement of the slicing capacity at motor speeds of 500 to 900 rpm. Figure 4a is the result of the first experiment using rpm 500-700. Figure 4b shows the result of the second experiment with rpm 700-900. From the results of both, it appears that the slicing capacity increases consistently with increasing rpm that is in accordance with predictions. At motor speed of 900 rpm and speed ratio of 3.9:1, the slicing disc rotate at about 230 rpm or 3.85 cycles/s. With three blades on the disc, the estimated slicing speed was 3.85 x 3 ≈ 11.5 slices/s or about 692 slices/min.

3.2.2. Slicing quality

The quality of the slices was assessed from the suitability of the slice thickness and the percentage of intact slices. Table 4 shows the data on the results of calculating the average slice thickness. From the table, it can be seen that the slice thickness is relatively the same at all rotational speeds. This shows that rpm does not affect the thickness of the slices. These results are in accordance with the prediction that the thickness of the slices is not determined by the speed but by the adjustment of the knife attachment to the disc. The results of the slice thickness using this slicing

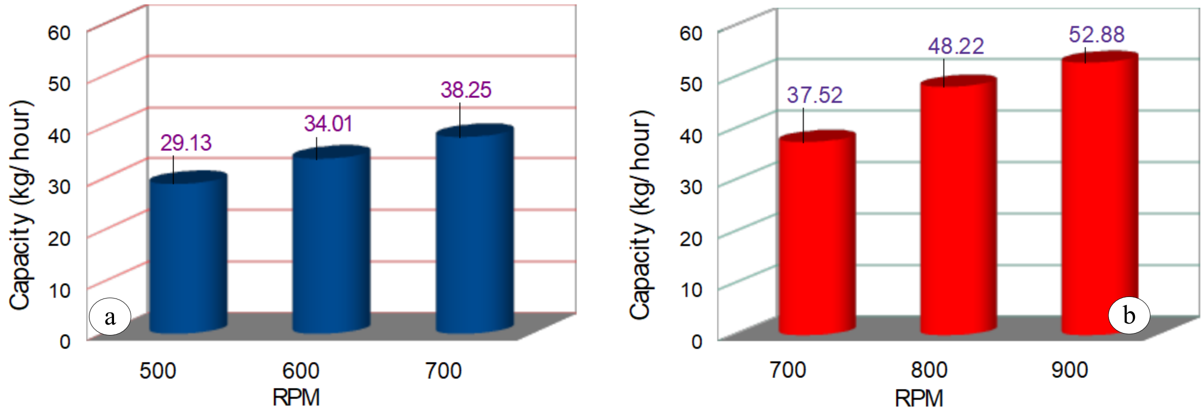

Figure 4. Slicing capacity (a: result from first experiment, using tempeh "A"; b: result from second experiment, using tempeh "B")

Table 4. Average slice thickness

Test	Material	Setup speed (rpm)	Average thickness (mm)
1	A	500	1.12
2		500	1.08
3		500	1.06
4		600	1.07
5		600	1.13
6		600	1.09
7		700	1.11
8		700	1.12
9		700	1.13
		Average A	1.10 ± 0.027
10	B	700	1.1
11		700	1.09
12		700	1.08
13		800	1.08
14		800	1.07
15		800	1.1
16		900	1.06
17		900	1.07
18		900	1.07
		Average B	1.08 ± 0.014

machine are in accordance with the thickness of the tapioca tempeh chips material required by the industry, which is around 1 mm. Tempeh slices with the thickness of 1 mm will produce crispy fried chips but are still firm enough so that they do not break easily in the packaging.

The results of sorting and weighing the sliced results based on intactness are shown in Table 5. Meanwhile, the appearance of the intact sliced results is shown in Figure 5. The numbers appearing in the rightmost column of Table 5 show that in the experiment conducted, intact slices were not affected by the difference in rpm. The most influential factor in the greater number of non intact or damaged slices was the material. Preparation of materials that was conducted manually resulted in varying material quality. In this experiment, in material A, when the mixture of fermented soybeans and tapioca flour was put into a plastic container, the compaction was somewhat uneven so that the tempeh was more easily damaged. Material B were prepared more carefully so that their quality were better.

Table 5. Percentage of intact slices

Test	Material	Setup speed (rpm)	Sample weight (g)	Intact slices	
				(g)	%
1		500	133	119	89.5
2		500	141	137	97.2
3	A	500	135	124	91.9
4		600	126	123	97.6
5		600	136	125	91.9
6		600	131	121	92.4
			Average		93.4 ± 3.26
7		700	405	385	95.1
8		700	437	420	96.1
9		700	390	368	94.4
10		800	434	410	94.5
11	B	800	397	382	96.2
12		800	392	379	96.7
13		900	390	382	97.9
14		900	434	422	97.2
15		900	442	432	97.7
			Average		96.2 ± 1.34

Figure 5. Intact slices

3.2.3. Power consumption

The average of the electric power consumption reading results on the data logger for each experiment are given in Table 6. While Figure 6 shows the average power consumption at each different speed. Figure 8 shows a consistent increase in idle power as the motor speed increases. An interesting thing to note from the figure is that the idle power of this machine is very low. Apart from the BLDC “servo” motor factor, the simple power transmission consisting of only one-step reduction using a pair of pulleys contributes to the low idle consumption. Moreover, the use of an M-type V-belt also helps reduce power losses in the transmission.

The cutting power requirement increases with the increase in the experimental speed range. This is in accordance with the prediction because at higher rpm, the cutting by the knives on the material occurs faster. The figure also shows a rather large increase in power consumption between rpm 700 and 800 which was caused by the difference in the materials used. Cutting data at rpm 800 and 900 used material "B". This material has a more homogeneous density so it requires higher power for slicing.

Table 6. Power consumption

Test	Setup speed (rpm)	Sample Tempeh	Idle power consumption (average, W)	Power consumption while slicing (average, W)	Actual power consumption (e-d, W)
a	b	c	d	e	f
1			9.7	24.3	14.6
2	500	A	9.8	21.6	11.8
3			9.7	23.1	13.4
		Average	9.73 ± 0.06	23.0 ± 1.35	13.27 ± 1.40
4			11.6	25.6	14.0
5	600	A	11.5	23.1	11.6
6			11.3	25.2	13.9
		Average	11.47 ± 0.15	24.63 ± 1.34	13.17 ± 1.36
7			13.0	35.5	22.5
8	700	A	13.1	35.8	22.7
9			13.1	35.1	22.0
		Average	13.07 ± 0.06	35.47 ± 0.35	22.40 ± 0.36
10			15.6	53.29	37.69
11	800	B	15.5	52.4	36.9
12			15.5	58.0	42.5
		Average	15.53 ± 0.06	54.56 ± 3.01	39.03 ± 3.03
13			17.0	58.81	41.81
14	900	B	17.0	65.57	48.57
15			17.3	54.26	36.96
		Average	17.10 ± 0.17	59.68 ± 5.50	42.45 ± 5.64

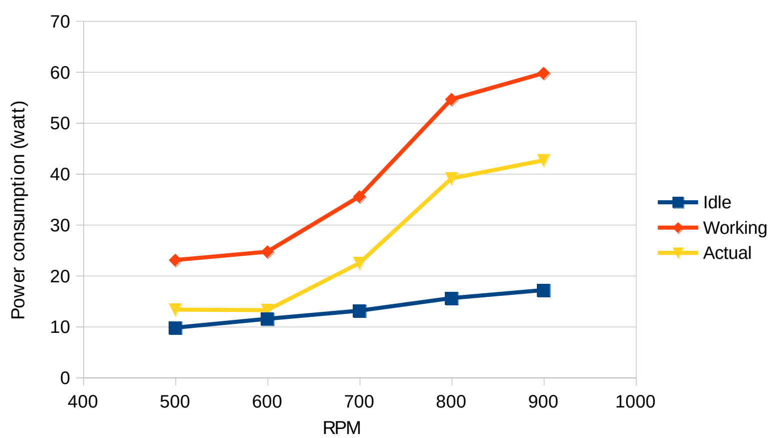

Figure 6. Slicing electrical power consumption

3.3. Evaluation of the Design of the Machine

The shortcomings of the machine observed during manufacturing, functional and performance testing are as follows.

1. The selected diameter of the main shaft (19 mm) is still too small so that it is not completely straight. As a result, the rotation of the slicing disc looked a little wobbly. Although when slicing using a hand push, the wobbly disc does not affect the slicing results too much, but for further development using a mechanical pusher, the disc rotation is needed to not wobble. For further improvements, it is necessary to consider using a shaft with a larger diameter.

2. The shaft material made of LCS is quite easy to rust so it is quite troublesome when it has to be dismantled because the bearings and pulleys are rather difficult to remove. For that reason, it is necessary to consider replacing it with a stainless steel shaft which is also quite easily available on the market.

3. The installation of the blade on the disc using a recessed bolt forces the placement of the tempeh to be at the right distance from the center of rotation. This is a bit troublesome when adjusting the tempeh inlet tube. For further improvement, it is necessary to consider the use of countersunk head bolts, although the installation method is not as easy as recessed head bolts.

4. Making holes in the disc using laser cutting does produce smooth cuts, but for making machines at the small workshop level it is impractical because it is expensive and the materials must be taken to a workshop that has the equipment. Cutting with a plasma cutting machine is more worthy of consideration because the results are quite good although not as smooth as laser cutting. However, with further smoothing using a file, a fairly smooth hole can be obtained. In terms of price, plasma cutting machines are quite affordable for small workshops.

Meanwhile, the advantages of this designed machine are as follows.

1. Very low power consumption because it uses a BLDC "servo" motor. The power consumption is much lower than using an induction motor. Likewise, the sound and vibration produced are very minimal so it is quite comfortable to use in small spaces.

2. Good and uniform slicing results and high capacity compared to slicing with other types of machines.

3. The machine can be used to slice various chip ingredients with a good results, so it has the potential to be developed into a multi-purpose chip slicer.

4. CONCLUSION

The new design of the tempeh tapioca slicing machine has been successfully made and functions well. The machine has three curved knives mounted on a stainless steel plate. The design is better than the previous machine. The thickness of the sliced results of approximately 1 mm is in accordance with the needs requested by the industry. The machine produces intact slices up to 96% with a slicing capacity of up to 53 kg/h (692 slices/min). The electric power consumption of the machine is very low, ranging from 23 W (at 500 rpm) to 60 W (at 900 rpm). In the functional test, it was found that the machine can be used to slice several types of chip materials well. Therefore it has the potential to be developed into a multi-purpose chip slicer. Suggestions for further improvement are replacing the shaft with stainless steel with a larger diameter, replacing the knife mounting bolts with countersunk head bolts, and cutting the disc material using a plasma cutter.

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