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Application of Mechanical Design Methods in the Development of a Shiitake Mushroom Stem Grinder for Semi-Industrial-Scale Production of Mushroom Floss

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Abstract:

Shiitake mushroom stems are nutrient-rich by-products, but they are often discarded or processed inefficiently because specialized equipment for fiber separation is limited. This study applied mechanical design methods to design, fabricate, and evaluate a shiitake mushroom stem grinder for semi-industrial-scale mushroom floss production. The prototype was developed with a 5 kg batch capacity, a 1.1 kW single-phase electric motor operating at 1450 rpm, a 280 mm blade rotation diameter, a 300 mm grinding container diameter, and a 460 mm grinding container height. Experimental tests using 1, 3, and 5 kg batches showed an average practical productivity of 60.01 kg/h. The machine operated stably under both no-load and loaded conditions, produced separated mushroom fibers suitable for mushroom floss processing, and allowed convenient blade removal and product discharge. The results indicate that the proposed grinder can improve the utilization of shiitake mushroom stem by-products and provide a practical processing option for small- and medium-scale facilities.

Keywords: *Shiitake mushroom stem; mushroom floss; grinding machine; mechanical design; by-product utilization*

I. INTRODUCTION

Shiitake mushrooms are an agricultural commodity of high economic and nutritional value. Studies indicate that the mushroom stems contain numerous valuable active compounds, such as beta-glucan and lentinan (which support immune system enhancement), along with an abundant content of proteins and minerals. However, due to their inherently tough and rigid mechanical properties, the stems are often discarded or ground using non-specialized machinery. This leads to low productivity, inconsistent output, excessive fragmentation, and high labor costs [1].

To improve the utilization of this by-product for the production of high-value vegetarian foods (such as shredded mushroom floss), the development of specialized fiber-shredding equipment is an urgent practical requirement for the industry.

Figure 1. *Dried shiitake mushroom stems used as an illustrative image [2]*

Figure 2. *Stir-fried shiitake mushroom stem floss with seaweed [3]*

Currently, Vietnamese research directly related to the design and fabrication of shiitake stem shredding machines remains limited. Nevertheless, several studies and publications have addressed the production process of shiitake mushroom powder, focusing on the drying and milling stages, as well as its applications in food processing and the extraction of bioactive compounds.

Previous studies and technical sources have addressed shiitake mushroom processing mainly through powder production, drying, and general processing equipment. Research on shiitake mushroom powder production has reported processing procedures for Lentinus edodes materials [1], while technical resources have described mushroom drying and mushroom-stem grinding equipment used in food processing

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[4,5]. More recently, Wang et al. (2025) designed and tested a secondary shearing device for Lentinus edodes stems, indicating the relevance of targeted mechanical equipment for stem utilization [6].

In terms of grinding technology, Zhang et al. (2012) demonstrated that mechanical grinding and jet milling effectively reduced particle size and significantly increased the soluble dietary fiber content in shiitake mushrooms compared with conventional shear pulverization methods [7]. In addition, Gong et al. (2022) evaluated the effect of superfine grinding on three mushroom powders, including Lentinus edodes, Hericium erinaceus, and Cordyceps militaris, and reported improvements in the functional properties of edible mushroom powders [8]. Yan et al. (2026) investigated the effects of steam explosion, wet pulverization, and superfine grinding on the physicochemical and functional properties of Lentinula edodes fruiting body powder, showing that pulverization and modification treatments can enhance the functional value of shiitake mushroom powder and support the development of mushroom-based food products [9]. Supakarn et al. (2018) investigated the drying behavior of shiitake mushrooms using a vacuum heat-pump dryer and reported that increasing the drying temperature accelerated moisture removal and reduced the equilibrium moisture content. The Peleg model accurately described the equilibrium moisture content, whereas the Midilli model showed the best performance in predicting thin-layer drying behavior [10].

Several studies in Vietnam and around the world have investigated the processing and utilization of shiitake mushroom (Lentinula edodes) and other edible mushroom powders. These findings demonstrate that appropriate size-reduction technologies can improve the functional and nutritional value of mushroom materials. However, most existing studies have focused mainly on the physicochemical and functional properties of mushroom powder after grinding, while limited attention has been given to the mechanical design and development of grinding equipment specifically for shiitake mushroom stems, especially for semi-industrial-scale production of mushroom floss. Therefore, this study aims to design, fabricate, and evaluate a practical grinding machine that can improve the utilization of shiitake mushroom stem by-products and support small- and medium-scale production. The novelty of this study lies in integrating mechanical design principles with the development of a compact grinder specifically intended for semi-industrial mushroom floss production using shiitake mushroom stems.

II. METHODOLOGY

The research methods of this study include information collection, inheritance, and synthesis of findings from domestic and international authors, experimental testing on the machine, and sensory evaluation of the shiitake mushroom stem product. In addition, the study applies a five-point Likert scale to evaluate the level of consumer preference for the product [11].

2.1. Operating principle of the shiitake mushroom stem grinder

The shiitake mushroom stem grinder was designed based on the criteria of compact structure, stable operation, and strict compliance with food safety and hygiene requirements. The main components of the machine are described in Figure 3.

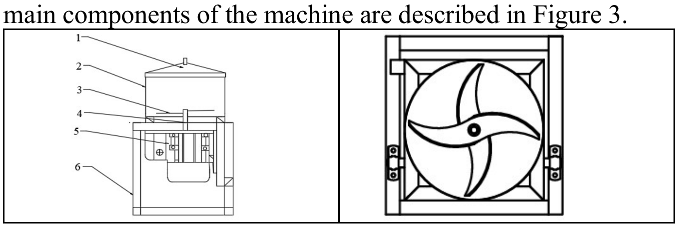

Figure 3. *Structural diagram of the machine*

1. Cover; 2. Container; 3. Grinding blade; 4. Shaft coupling; 5. Motor; 6. Machine frame

The operating principle of the shiitake mushroom stem grinder is as follows. Before operation, the grinding blade (3) is mounted onto the shaft, and the raw material is then loaded into the grinding chamber or container (2). When the motor (5) is switched on, the coupling (4) transmits rotational motion to the shaft, causing the grinding blade (3) to rotate. As a result, the mushroom stem material is gradually reduced in size. The grinding process continues for a certain period until the material reaches the required particle size. The processed material is then discharged through the machine frame (6), which is designed with a rotating mechanism to facilitate material removal.

2.2. Basis for Calculation and Selection of Machine Parameters

2.2.1. Calculation and Selection of the Electric Motor

The productivity of the milling machine is calculated using Equations (1), (2), and (3).

$$Q = \frac{M_t \cdot V \cdot \gamma}{T} \quad (1)$$

$$V = \frac{m}{M_1} \quad (2)$$

$$T = t_1 + t_2 \quad (3)$$

Where:

m = 5 (kg): mass of one grinding batch;

Mr (kg/m³): density of the food mixture;

Mt (kg/m³): bulk density of the food mixture;

V (m³): volume of the shiitake mushroom stalks within the grinding chamber;

T (min): total time required for grinding, loading, and unloading the product;

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t1 = 3 (min): time required for the grinding process;

t2 = 1 (min): time required for loading and unloading the product.

x = 1: volumetric utilization factor of the grinding chamber.

Substituting the aforementioned values into the equations, the productivity of the machine was calculated to be Q = 60 kg/h. The cutting torque acting on the shaft is calculated using Equation (4):

$$M_{ct} = \frac{4.P.D}{2} + F.\frac{D}{2} \qquad (4)$$

Given P = 45.4 (N) and D = 0.24 (m), the cutting torque is calculated as Mct = 22.59 N·m. The theoretical power is calculated using Equation (5):

$$N_{lt} = \frac{M_{ct}.\omega_{dao}}{\mu} \qquad (5)$$

Given Mct = 22.59 N·m and ωdao = 1450 rpm, the calculated theoretical power is Nt = 1.02 kW. The electric motor power is determined using Equation (6):

$$N_{dc} = \frac{N_{lt}}{\mu} \qquad (6)$$

With a bearing efficiency of μ = 0.99, the required motor power is calculated as Ndc = 1.03 kW. Based on standard specifications provided in the design manuals, a single-phase electric motor (50 Hz) with a rated power of P = 1.1 kW (equivalent to 1.5 HP) and a rotational speed of 1450 rpm is selected.

2.2.2. Calculation of Container Dimensions

The volume of the container is determined based on the batch mass and the bulk density of the material, taking into account a volumetric utilization factor to prevent overloading and ensure grinding efficiency. The container volume is calculated using Equation (7):

$$V_t = \frac{M_t}{M_r} \qquad (7)$$

Where:

Mt = 5 (kg): maximum mass of the material per grinding batch;

Mr = 1.1 kg/dm³: density of the material.

Substituting the values, Vt = 4.545 L is obtained. Given that the rotational diameter of the blade is 28 cm, the inner diameter of the container is selected as 30 cm. The effective volume of the container and the height of the material layer are determined according to Equations (8) and (9):

$$V_t = \pi.R^2.h \qquad (8)$$

$$h = \frac{V_t}{\pi.R^2} \qquad (9)$$

Substituting the values gives h = 11.96 cm. A design height of h = 20 cm is selected. The volume of the shaft for mounting the grinding blades (V1) and the volume of the blades (V2) are calculated using Equations (10) and (11):

$$V_1 = s_1.d_1 \qquad (10)$$

$$V_2 = s_2.d_2 \qquad (11)$$

The total volume of the internal shaft (Vtruc) and the total required internal volume of the container (Vtong) are calculated using Equations (12) and (13):

$$V_{truc} = V_1 + V_2 \qquad (12)$$

(1)

$$V_{tong} = V_{truc} + V_t \qquad (13)$$

Subs ructural parameters, $V_{tong} \approx 30.5$ L is obtained. After rounding up, the final container volume is selected as $V_{thung} = 31$ L. Consequently, the total height of the container is calculated using Equation (14):

$$h_{thung} = \frac{V_{thung}}{S_{thung}} \qquad (14)$$

Substituting the values, the container height is determined to be $h_{thung} = 46$ cm.

2.2.3. Dimensions of the Container Lid

The container lid is designed in a conical shape with a diameter of 30 cm and features an integrated top handle for easy operation.

2.2.4. Material Selection for the Container

The container material is selected as SUS 304 stainless steel to ensure food hygiene and safety standards. The density of SUS 304 stainless steel is 7.8 tons/m³ (7800 kg/m³).

TABLE 1. *CHEMICAL COMPOSITION OF SUS 304 STAINLESS STEEL*

Grade	C	Cr	Ni	Ti	Mn	Si	P(max)	S(max)
304	< 0.08	18-10	8-10	-	< 2,0	< 1.0	0.045	0.03

2.3. Shaft Design

2.3.1. Shaft Coupling

A rigid sleeve coupling made of C45 steel was selected to rigidly connect the motor shaft and the blade shaft. The nominal torque transmitted through the shaft is calculated as:

$$T = 9.55 \times 10^6 \times P / n \qquad (15)$$

Substituting P = 1.1 kW and n = 1450 rpm gives T = 7244.83 N·mm. The calculated design torque considering the dynamic load factor is determined by Equation (16):

$$T_t = K.T \qquad (16)$$

Where:

K is the machine operating factor, chosen as K = 1.5;

T is the nominal torque on the shaft;

Substituting the values gives Tt = 1.5 × 7244.83 = 10867.25 N.mm ≈ 10.87 N.m. The selected coupling dimensions are: outer diameter D = 35 mm, inner diameter d = 24 mm, and pin diameter dc = 12 mm.

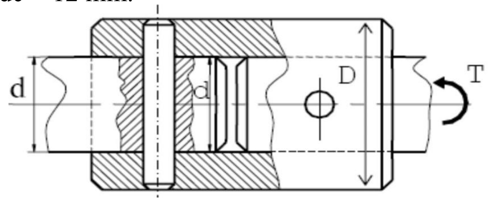

Figure 4. Structure of the sleeve coupling

2.3.2. Preliminary Shaft Calculation and Diameter Estimation

The shaft material is selected as C45 steel with an allowable shear stress [τ] = 15 MPa. The preliminary shaft diameter is determined using the following torsional formula (17)

$$d_k = \sqrt[3]{\frac{T_k}{0{,}2[\tau]}} \qquad (17)$$

Substituting the values gives d = 13.4 mm. To ensure safety under dynamic loads and fatigue resistance during high-speed operation, the actual shaft diameter is selected as d = 25 mm with a shaft length of 85 mm. Safety factor verification for fatigue endurance gives n = 5.08 ≥ [n] = 1.895, indicating that the selected shaft diameter satisfies the strength requirement. The actual operating productivity of the machine is evaluated using Equation (18) [12]

$$N = 3600.\ m/t \ \ (kg/h) \qquad (18)$$

2.4. Method for Evaluating Product Preference

To evaluate the level of product preference using a Likert scale, a sensory evaluation was conducted with 30 volunteers. The participants assessed the product based on several criteria, including color, aroma, texture, appearance, and convenience. The evaluation was carried out using a survey questionnaire, as presented in Table 2.

TABLE 2. FIVE-POINT LIKERT SCALE USED FOR SENSORY EVALUATION

Score	5	4	3	2	1
Description	Very Good	Good	Average	Poor	Very Poor

III. RESULTS AND DISCUSSION

3.1. Design and Fabrication of Main Components

Shredding blade system: Instead of utilizing conventional straight blades, the research team implemented a curved blade design comprising two blades that form four cutting edges. The curved design enhances the sliding shear capability, effectively shredding the mushroom fibers without crushing the raw material. Additionally, this configuration ensures a more uniform distribution of the load applied to the machine shaft. The blades are fabricated from 304 stainless steel.

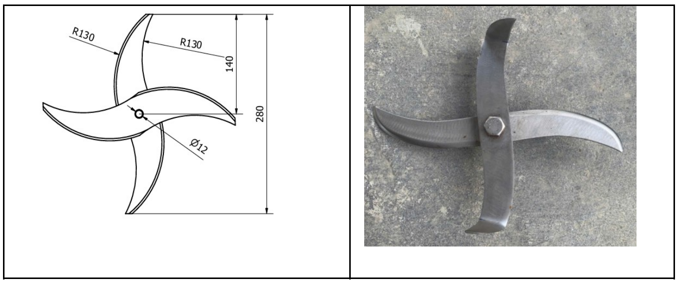

Figure 5. Designed and fabricated cutting blade

Material hopper: The material hopper was fabricated from SUS 304 stainless steel to meet food hygiene requirements. The hopper has a diameter of 300 mm and a height of 460 mm, with a grinding capacity of 5 kg per batch.

Machine frame: The machine frame was constructed from 30 × 30 × 1.2 mm square steel tubes to ensure structural strength and stability during operation. A notable improvement of the frame design is the integration of a rotating hinge mechanism, which allows the operator to easily tilt the hopper and quickly discharge the processed material after grinding.

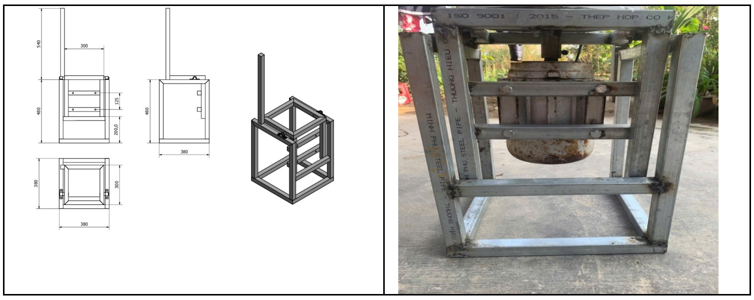

Figure 6. Designed and fabricated machine frame

Machine shaft: The rotating shaft of the machine was fabricated with a diameter of 25 mm. The total length of the shaft, including the coupling section connected to the motor, is 85 mm. One end of the shaft is directly connected to the motor shaft, while the other end was machined with an M12 thread for mounting the cutting blade.

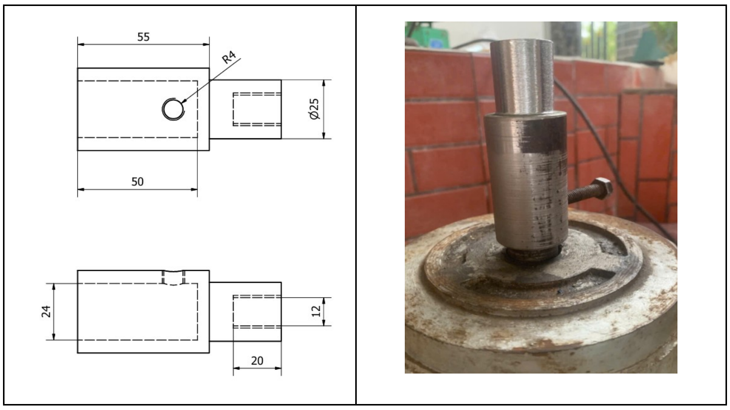

Figure 7. Designed and fabricated rotating shaft

Design and fabrication of the container and lid

The container was designed with a diameter of d_1 = 300 mm and a height of h_1 = 460 mm. At the center of the container bottom, a hole with a diameter of 25 mm was machined for shaft installation.

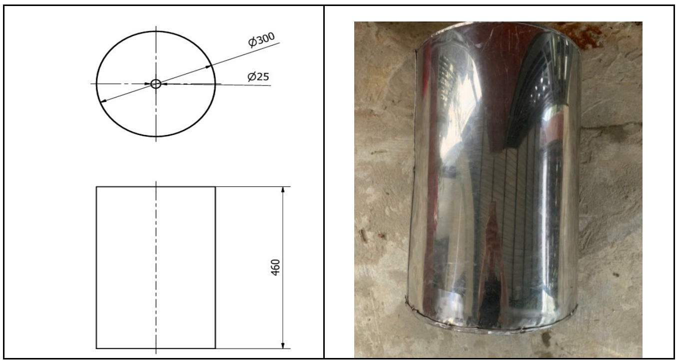

Figure 8. *Designed and fabricated container*

Based on the design calculation, the lid of the material container was fabricated with a diameter of d = 298 mm. A handle was installed on the top of the lid to facilitate opening, closing, and handling during operation.

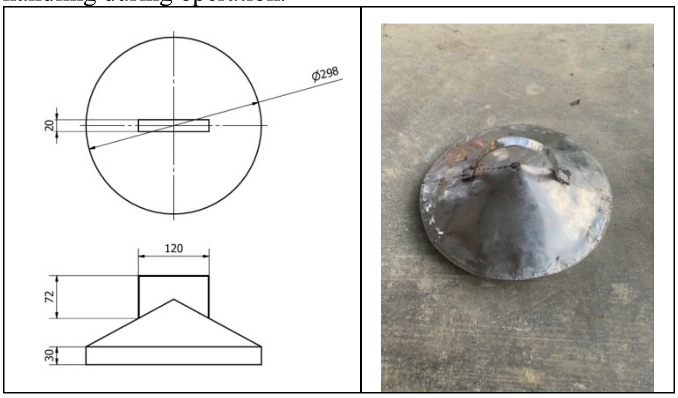

Figure 9. *Designed and fabricated lid*

Figure 10. *Fabricated container*

After studying, designing, and fabricating the shiitake mushroom stem grinder for mushroom floss production, the machine prototype with a capacity of 5 kg per batch was tested at the workshop of the Faculty of Engineering and Technology.

Figure 11. *Complete assembly of the machine*

Table 3 summarizes the main structural specifications and operating parameters of the developed shiitake mushroom stem grinder. These parameters were determined based on the design calculations and the fabricated prototype.

TABLE 3. *SUMMARY OF STRUCTURAL AND OPERATING PARAMETERS OF THE MACHINE PROTOTYPE*

No.	Component / Parameter	Specification
1	Machine capacity	5 kg/batch
2	Rotational speed	1450 rpm
3	Cutting blade rotation diameter	280 mm
4	Cutting blade cross-section	15 (mm)
5	Grinding container diameter	300 (mm)
6	Grinding container height	460 (mm)
7	Electric motor	1.5 HP – 1.1 kW
8	Machine weight	25 kg
9	Machine dimensions	380 × 380 × 480 mm

3.2. Experimental Testing and Evaluation

3.2.1. Material Preparation

A total of 5 kg of dried shiitake mushroom stems was used as the raw material. The stems were pre-treated and soaked in warm water at 40–50°C for 30–40 minutes. After soaking, the material was drained for 5–10 minutes. The average weight after soaking and draining reached approximately 10–12 kg, which provided a suitable condition for grinding and processing into mushroom floss.

Figure 12. *Shiitake mushroom stems before and after soaking: (a) before soaking; (b) after soaking*

3.2.2. Quality Requirements for the Final Product

The product obtained after grinding should meet the required quality standards. The mushroom fibers should be well separated, free from clumping, and relatively uniform in size, making them suitable for producing mushroom floss. The grinding process should ensure that the mushroom fibers are not overly crushed due to excessive grinding time, while maintaining their natural color without darkening caused by excessive heat generation during machine operation. In addition, the product must be free from metal contaminants to ensure food safety and should be suitable for subsequent processing stages such as roasting, drying, and mixing.

3.2.3. Working Performance Test of the Machine

After the machine was tested under no-load operating conditions, all components were found to operate safely and stably. The machine was then operated under loaded conditions, stopped, and inspected to evaluate its working performance. The results showed that the machine structure had sufficient rigidity and operational stability, while the working mechanism met the design requirements and effectively ground the supplied shiitake mushroom stems. In addition, the machine operated smoothly with low noise, the grinding container and motor assembly could be tilted and adjusted as required to facilitate material discharge and handling, and the cutting blade could be easily installed and removed, making cleaning and maintenance more convenient.

3.2.4. Experimental Procedure

The machine was tested using input batches of 1, 3, and 5 kg. For each batch size, two trials were conducted, and the average value was calculated. The recorded grinding times were 60–61 s for 1 kg, 181–185 s for 3 kg, and 291–294 s for 5 kg. Productivity was then calculated using Equation (18).

TABLE 4. PRODUCTIVITY TEST RESULTS OF THE SHIITAKE MUSHROOM STEM GRINDER

Trial	Tested mass (kg)	Time (s)	Productivity (kg/h)
1	1	60	60.00
2	1	61	59.00
Mean (1 kg)			59.50
3	3	185	58.37
4	3	181	59.66
Mean (3 kg)			59.01
5	5	291	61.85
6	5	294	61.22
Mean (5 kg)			61.53
Average productivity (kg/h)			**60.01**

The developed shiitake mushroom stem grinder demonstrated stable operation and satisfactory processing performance under all tested loading conditions. The average productivity of 60.01 kg/h indicates that the proposed design is suitable for semi-industrial mushroom floss production while maintaining a compact structure and relatively low manufacturing cost. Compared with conventional manual shredding or the use of general-purpose grinders, the developed machine provides more uniform fiber separation and reduces processing time and labor requirements.

Similar observations have been reported by Wang et al. (2025), who demonstrated that secondary shearing mechanisms improved the utilization efficiency of Lentinus edodes stems by enhancing fiber separation while reducing mechanical damage to the material. Likewise, Zhang et al. (2012) reported that grinding technology strongly influences the structural characteristics of mushroom products, with appropriate mechanical action leading to improved product quality and functional properties.

Figure 13. *Ground shiitake mushroom stem samples after different soaking times: (A) 20 min; (B) 30 min; and (C) 40 min*

The soaking treatment also played an important role in the grinding process. Mushroom stems soaked for approximately 30 min exhibited suitable softness while maintaining sufficient structural integrity for effective fiber separation. Insufficient soaking (20 min) resulted in incomplete hydration and lower grinding efficiency, whereas excessive soaking (40 min) caused excessive softening and partial destruction of the fibrous structure. These observations agree with previous studies indicating that the moisture content of mushroom materials strongly affects their mechanical properties and processing behavior. Supakarn et al. (2018) demonstrated that moisture equilibrium significantly influences drying characteristics and material properties, suggesting that proper moisture conditioning before mechanical processing can improve processing efficiency.

TABLE 5. PRELIMINARY MATERIAL COST OF THE SHIITAKE MUSHROOM STEM GRINDER

Material / component	Unit price (thousand VND)	Quantity	Amount (thousand VND)
30 x 30 x 1.2 mm square steel tube	26/m	7 m	182
Cutting blade	150	2 blades	300
SUS 304 sheet (0.4 mm thick)		92 x 96 cm	286
Bearing, 25 mm diameter	30	1 piece	30
Round steel bar, 36 mm diameter	20	1.5 kg	30
Electric motor, 1.1 kW		1 piece	1200
Bolts, nuts, and washers (M10, M8)		8	50
Additional fabrication consumables (grinding stones, cutting blades, drill bits, welding rods, etc.)			150
Fabrication labor			500
Total			2728

Table 5 presents the preliminary material and fabrication costs of the developed shiitake mushroom stem grinder. The estimated total cost of the prototype was approximately 2,728 thousand VND, with the electric motor representing the largest proportion of the overall cost. Other major expenses included the stainless-steel sheet, cutting blades, fabrication labor, and additional fabrication consumables. The relatively low manufacturing cost demonstrates that the proposed grinder can be fabricated using commercially available materials and standard machining processes, making it economically feasible for small and semi-industrial mushroom processing enterprises. Compared with commercially available mushroom grinding machines, the developed prototype can be manufactured at a substantially lower cost while still satisfying the functional requirements for mushroom floss production. However, this study focused on the mechanical design and preliminary performance evaluation of the grinder. Product quality attributes, energy consumption, and long-term durability were not comprehensively investigated and should be addressed in future studies.

IV. CONCLUSION

This study applied mechanical design methods to develop a specialized shiitake mushroom stem grinder for semi-industrial-scale vegetarian mushroom floss production. The fabricated prototype has a compact structure, safe operation, and convenient handling, making it suitable for small- and medium-scale production facilities. The machine has a 5 kg batch capacity and achieved an average practical productivity of 60 kg/h under the tested conditions. The prototype operated stably under no-load and loaded conditions, produced separated mushroom fibers suitable for mushroom floss processing, and allowed convenient blade removal and product discharge. The results indicate that the proposed grinder provides a practical solution for improving processing efficiency, reducing labor requirements, and adding value to shiitake mushroom stem by-products. Future studies should optimize operating parameters, evaluate product quality after grinding, and assess long-term durability under continuous operation.

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