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Development of Flat Burr Coffee Grinding Machine for Small and Medium Enterprises Scale

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Abstract. *This study was conducted to develop an improved coffee grinder tailored for small and medium enterprises (SMEs) to address challenges due to limited resources. The development phase included a broad description, sizing, defining main components, developing technical drawings, manufacturing, and conducting functional tests. The machine had an overall dimension of 743 mm in length, 367 mm in width, and 580 mm in height. It was powered by a 1 HP induction motor with a rotation speed of 1400 rotations per minute (RPM) and a shaft diameter of 19 mm. The prototype achieved a grinding capacity of 23.8 kg/h for acceptable coffee grounds while maintaining a constant grind size, essential for achieving the best flavor and aroma. However, the noise level reached 86.5 dB, requiring hearing protection for prolonged usage. Future investigations should focus on exploring alternative materials and developing noise mitigation strategies, as noise reduction efforts can enhance operator physical and mental health in the coffee production process.*

Keywords: *development; flat burr coffee grinding machine; optimizing; small and medium enterprises (SMEs).*

Type of the Paper: Regular Article.

1. Introduction

Small and Medium Enterprises (SMEs) are renowned for playing a significant role in various stages of coffee production, from growing and harvesting to processing and distribution. The functions include contributing to local economies, job creation, and the promotion of sustainable practices [1–6]. However, SMEs often face unique challenges due to the size and resource limitations, which affect the ability to innovate and compete with larger enterprises.

An example of the challenge is the noise level of existing flat burr grinders, which can exceed safe limits for prolonged use. This potentially creates health and safety concerns for operators in small workshops and roasting facilities, leading to hearing loss and tinnitus. Additionally, exceeding noise regulations can result in fines or operational restrictions. There are various categories of coffee size reduction tools, such as blade grinders, burr grinders, and disk mills. One of the advantages of using a burr mill is the ability to consistently produce a uniform grind size, which is essential for extracting ideal flavor. Burr mills also offer a larger variety of grind sizes that can be adjusted to fit different brewing processes. Furthermore, compared to blade grinders,

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burr mills are often quieter in operation. There are two distinct types of burr grinders namely flat and conical. Flat burr grinders yield a highly uniform grind and are well-suited for espresso as well as other brewing methods that need precision [7].

In the coffee industry, flat burr coffee grinders are essential equipment for SMEs engaging in coffee production. These grinders are used to achieve a consistent grind size, which is crucial for the flavor and aroma of the coffee [8–11]. However, developing flat burr coffee grinding machines for SMEs poses several challenges that must be addressed to optimize efficiency and effectiveness. One of the main challenges SMEs face in developing flat burr coffee grinding machines is limited resources and expertise in adapting as well as integrating new technologies [12–15]. A significant study gap is a lack of understanding and resources for adoption by local SMEs.

The pursuit of achieving a superior coffee grind is a complex undertaking, as demonstrated by several articles. Although several academics prioritize user experience through the development of innovative concepts for Mikma grinders or the creation of portable grinders with various coarseness settings [16,17], others concentrate on exploring the technical elements. A study investigated the correlation between processing conditions and particle size using a servo-controlled grinder [18], while another emphasized the significance of frame strength through stress analysis [19]. A comprehensive overhaul is suggested to enhance the coffee company production capacity and efficiency. These studies demonstrate the continuous advancement of coffee grinders, focusing on meeting user requirements, improving technical performance, and considering production factors.

There is a need to develop practical and innovative ideas to produce low-cost ground coffee while increasing the overall sustainability of the business. In addition, it is essential to consider the specific needs and challenges that SMEs face in different coffee industry sectors. A thorough study examining how technology is adopted in the coffee industry, considering the different types of businesses and industries, can help people develop valuable strategies and frameworks for SMEs to obtain excellent results from flat burr coffee grinders [20,21]. Furthermore, there is a need for effective strategies and tools that can assist SMEs in harnessing the benefits of digital technologies.

Addressing the current gaps would support SMEs in making informed decisions and navigating the complexities of technology adoption in developing flat burr coffee grinding machines [22,23]. By understanding the determinants of technology success in different sectors of the coffee industry, as well as the decision-making processes and challenges faced by management, it will be possible to develop effective strategies, frameworks, and tools to optimize the development of flat burr coffee grinding machines for SMEs [24]. Therefore, this study aimed to develop a user-friendly flat burr coffee grinding machine specifically designed to address the needs of SMEs in the coffee industry.

2. Materials and methods

2.1. The flat burr grinding machine development

The method used in developing the flat burr grinding machine is reengineering which requires making significant changes to existing equipment or systems to improve performance, efficiency, and effectiveness. These changes are not merely patches or fixes but a complete overhaul and rebuilding of the equipment or system. The process may include redesigning, updating technology, reconfiguring workflows, and implementing new strategies or approaches [25]. The development phase included a broad description, sizing, defining main components, developing technical drawings, manufacturing, and conducting functional tests [26–31]. Functional tests conducted comprise performance testing, compliance tests, and service tests. Performance tests were conducted on medium to dark-roasted Arabica and Robusta coffee.

2.2. Description of flat burr mill grinding machine design

A flat burr coffee grinder generally consists of several important components. Hopper, which is made of stainless steel, is the initial place for storing coffee beans before being ground. The main component of the grinder is the burr mill, consisting of two flat abrasive discs (burrs) that grind coffee beans to the required size. The speed and power of the motor that drives the burr mill impact the efficiency. This grinder is equipped with a grind setting dial that allows users to change the distance between the grinders, thereby affecting the size of the coffee grounds. The components are encased in the grinder chassis, and an on/off switch regulates the machine power. The outline design drawing is presented in Fig. 1, while the construction components of the flat burr mill grinding coffee machine are presented in Fig. 2, where (1) burr mill housing, (2) burr mill housing cover, (3) auger housing, (4) auger, (5) auger turning axle, (6) bearing, (7) spring, (8) burr mill, (9) grinder housing support, (10) smoothness regulator, (11) dispensing funnel, (12) intake funnel, and (13) crusher.

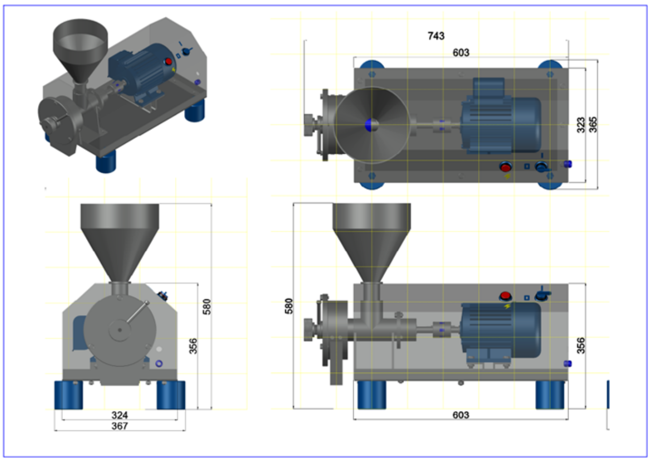

Fig. 1. Overall design of the flat burr mill grinding coffee machine (size in *mm*)

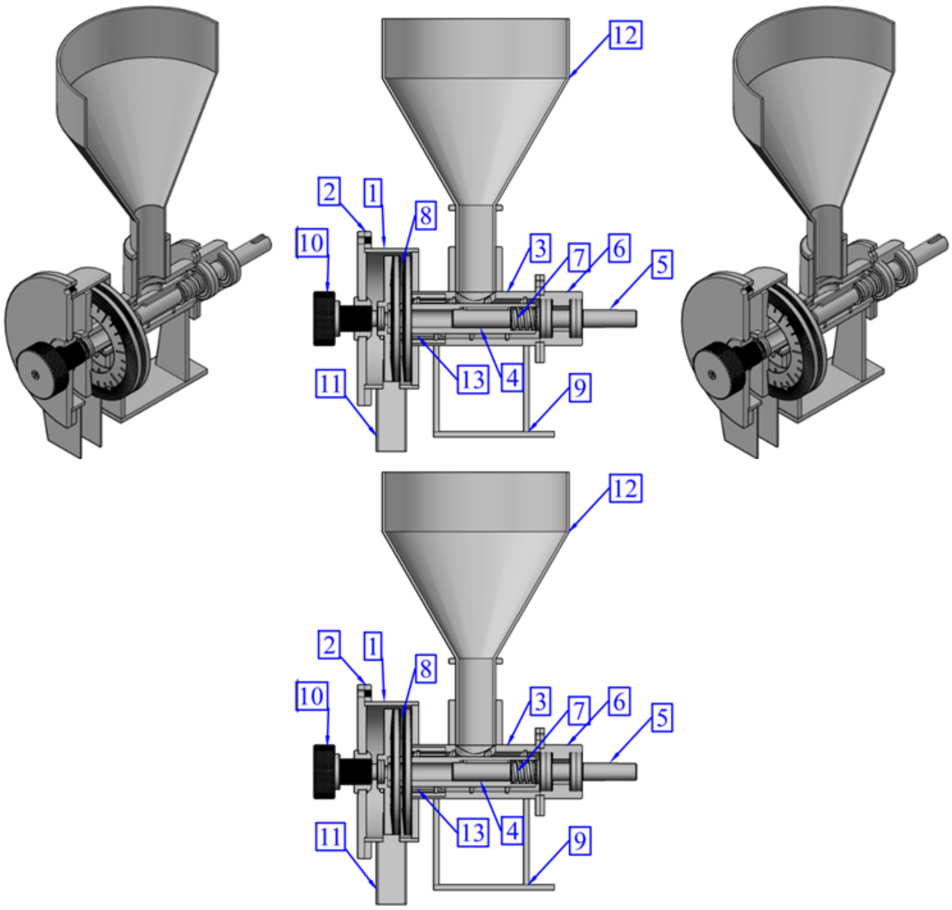

Fig. 2. Components of the flat burr mill grinding coffee machine: 1) burr mill housing, 2) burr mill housing cover, 3) auger housing, 4) auger, 5) auger turning axle, 6) bearing, 7) spring, 8) burr mill, 9) grinder housing support, 10) smoothness regulator, 11) dispensing funnel, 12) intake funnel, and 13) crusher

The materials used for construction were hopper redemption of stainless steel 0.8 mm, burr mill housing of stainless steel 3 mm, burr mill housing cover of stainless steel 11 mm, static and dynamic burr mills of steel, each with a thickness of 9 mm, burr mill shaft of steel with a diameter of 19.5 mm, dispensing funnel of stainless steel 1.2 mm, and frame of steel plate with a thickness of 4 mm.

2.3. Sizing of the main components

a) Capacity

Fig. 3 shows the effective area of coffee bean inclusion. To calculate capacity, the effective area of coffee bean should be calculated using Equation (1).

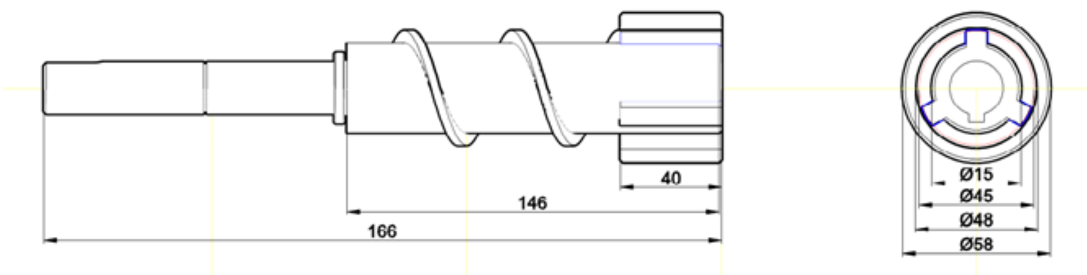

Fig. 3. The effective area of coffee bean inclusion

$$A_{ef} = \frac{\pi}{4}(A_1)^2 - \frac{\pi}{4}(A_2)^2 - 3\,(A_3)^2 \quad (1)$$
$$A_{ef} = \frac{\pi}{4}(48)^2 - \frac{\pi}{4}(45)^2 - 3\,(4)^2$$
$$A_{ef} = 171\ \text{mm}^2$$

From the calculation, the effective area of income of roasted coffee beans was found to be 171 mm^2. The average cross-sectional area of a roasted coffee bean is 35.97 mm [32]. This dimension allows approximately five beans (4.75 to be precise) to fit into the area of the burr mill, given the total amount of coffee that can enter this space is 171/35.97. Each roasted coffee bean weighs, on average, 0.17 g [32]. Consequently, the weight of the coffee beans that enter the burr mill amounts to 5 multiplied by 0.17 g, equating to 0.85 g.

The motor operates at 1400 rotations per minute (RPM) assuming the grinder efficiency is 80%. Therefore, the capacity can be calculated as follows: Q= 1400 ×0.85 × 0.8 g/min, resulting in Q= 0.952 kg/min or Q= 57.12 kg/h for coarse coffee ground. Taking into account an efficiency of 0.5 for achieving a fine coffee ground, the yield of powder that can be produced is approximately 23.8 kg/h.

b) Power Needed

Fig. 4 shows the flat burr mill illustration and dimension. The power required can be calculated using Equation (2).

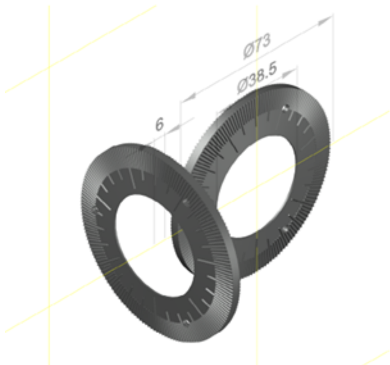

Fig. 4. Flat burr mill illustration with dimension

$$T = F \times r \quad (2)$$
$$T = (1 \times 9.80 \times 73)/(1000 \times 2)\ \text{Nm}$$
$$T = 0.3577\ \text{Nm}$$
$$\omega = \text{RPM} \times 2\pi / 60$$
$$\omega = 1400 \times 2\pi / 60 = 146.61\ \text{rad/s}$$
$$P = 0.3577\ \text{Nm} \times 146.61\ \text{rad/s} = 52.45\ \text{W}$$

Where: T is torsion (Nm), r is radius of burr mill (mm), F is mass of burr mill (N), ω is angular velocity (rad/s), P is required force (N).

2.4. Performance test

The conducted equipment testing included verification, performance, and continuous load tests. Verification tests were conducted on component parameters, including the income, mill house, and discharge part, as well as frame material. The performance test was carried out by assessing the grinding capacity, coffee yields that passed through 40.60 and 80 mesh sieves, the water content of the ground coffee, reduction in yield, as well as the presence of smoke and odor contamination. The continuous load test entailed subjecting the system to a constant load for a duration of 2 hours.

3. Results and Discussion

3.1. The prototype of a flat burr mill coffee grinding machine

The prototype of a flat burr mill coffee grinding machine developed in this study is shown in Fig. 5, and the specification of the machine is presented in Table 1.

Fig. 5. Designed flat burr mill coffee grinder Prototype.

Table 1. Specification of Flat burr mill coffee grinder

No	Parameter	unit	size
1	Overall dimension		
	a. Length	mm	743
	b. Width	mm	367
	c. Height	mm	580
2	Motor penggerak		
	a. Type	Induksi	
	b. Power	HP	1
	c. Rotation	RPM	1400
	d. Shaft diameter	mm	19
3	Unit Penggiling		
	a. Diameter of burr mill housing cover	mm	95
	b. Diameter of burr mill housing	mm	85
	c. Diameter of static burr mill	mm	73
	d. Diameter of dynamic burr mill	mm	73
	e. Width of disc teethC-D	mm	18
4	Transmission		
	a. Diameter of Cross joint D-E	mm	45.2
5	Feeding and dispensing unit		
	a. Feeder height	mm	490
	b. Inlet Funnel dimension (Ø×T)	mm	250 × 180
	c. Inlet hole dimension	mm	45
	d. Ejection hole dimension (p×l)	mm	70 × 30

3.2. Flat burr mill coffee grinding machine test

Performance tests were performed on the finest fineness adjustment settings and the conditions of the materials used are presented in Table 2.

Table 2. Average material condition

No	Parameter	Unit	Size	
			Arabica	Robusta
1	Moisture content	%	1.18	0.49
2	Length	Mm	11.4	9.6
3	Width	Mm	8.4	7.6
4	Thickness	Mm	5.8	4.8

The performance test showed that on average, the grinding capacity for Robusta was slightly higher at 20.58 kg/h compared to Arabica at 19.65 kg/h. In terms of the proportion of coffee that passed through different mesh sizes, 88.64% of Robusta and 86.73% of Arabica passed through a mesh size of 40. For a mesh size of 60, 53.16% of Robusta passed through, while Arabica had a slightly higher percentage at 56.30%. At a mesh size of 80, both varieties showed similar results, with 38.02% and 38.39% passing through respectively. Water content in the ground coffee differed significantly between the two varieties, at 0.72% and 0.29% respectively. The loss of results was also slightly higher for Arabica at 0.75%, compared to Robusta at 0.49%. Finally, neither Robusta nor Arabica had smoke or odor contamination, indicating the absence of undesirable factors in the grinding process for both coffee types. The absence of smoke and odor contamination ensures the quality and integrity of the ground coffee. Smoke and odor contamination are important aspects to control in the processing of ground coffee [33-35]. The presence of contamination can have detrimental effects on the quality of ground coffee, altering the taste and aroma, which makes it less appealing to consumers [36,37]. The performance test results data are presented in Table 3.

Table 3. Performance test results

No	Parameter	Unit	Average results	
			Robusta	Arabica
1	Grinding capacity	kg/h	20.58	19.65
2	Coffee that passes on mesh 40	%	88.64	86.73
3	Coffee that passes on mesh 60	%	53.16	56.3
4	Coffee that passes on mesh 80	%	38.02	38.39
5	Water content of ground coffee	%	0.72	0.29
6	Loss of results	%	0.49	0.75
7	Smoke and odor contamination	-	No	No

The continuous load test results showed that after 2 hours of testing, there were no changes in the structure of the components causing engine damage, and all components functioned stably. The test is essential for ensuring the reliable and efficient performance of equipment. Without the continuous load test, equipment may operate beyond its capacity, leading to equipment failure and potential safety hazards. Additionally, it allows for the identification of any weaknesses or vulnerabilities in the equipment, enabling proactive maintenance and repair measures to be taken. By continuously testing the load on equipment, operators can assess performance under different conditions and identify any potential issues or limitations. This helps to minimize downtime and maximize productivity by addressing any problems before escalating into major failures [38].

Although the service test found that one person operates the tool as shown in Table 4, adjusting and operating the tool is easy, with the noise factor being 86.50 dB.

Table 4. Service test results

No.	Parameter	Evaluation value
1	Setup	Easy
2	Ease of operation	Easy
3	Operator safety	Need protective equipment
4	Number of operators	1 person
5	Noise level	86.5

The noise measurement outcomes during the grinder operation were 86.5 dB. At 86.5 dB, the measured noise level of coffee grinder falls within the range of "busy restaurants or traffic noise at a distance." Although tolerable for short periods, this level can cause discomfort, annoyance, and difficulty concentrating with prolonged exposure. Studies by Amor et al. [39] and Flimel and Dupláková [40] further showed potential health concerns. Regular exposure to noise exceeding 85 dB can lead to temporary hearing issues such as tinnitus (ringing in the ears) and hearing fatigue (muffled hearing or temporary loss of sensitivity). These effects usually lessen in quiet environments but emphasize the importance of using safety measures including earplugs or noise-canceling headsets to protect operators hearing health during extended use.

The grinding noise level of 86.50 dB is sufficiently high to induce discomfort and may lead to temporary hearing issues including tinnitus and hearing fatigue [39,40]. For extended use, operators should utilize safety equipment such as earplugs (ear protection covering the entire ear or placed into the ear canal), or noise-canceling headsets (headsets with noise-cancellation technology).

4. Conclusions

In conclusion, the developed flat burr grinder prototype demonstrated promising functionality, achieving a grinding capacity of 23.8 kg/hr for fine coffee grounds. The quality of the grind, however, requires further evaluation through particle size distribution analysis to ensure consistency for optimal coffee extraction.

A significant point to address is the measured noise level of 86.5 dB. Although the grinder functions effectively, this noise level falls within the range that can cause discomfort, annoyance, and even temporary hearing issues with prolonged exposure.

Future study and development efforts should prioritize noise reduction strategies. This could entail exploring material selection for sound dampening, design modifications to minimize vibrations, or incorporating noise-isolating enclosures. Implementing these measures will ensure operator safety and comfort in a working environment while maintaining the grinder functionality and potential benefits for SMEs in the coffee industry.

The prototype generally demonstrates a promising foundation for a flat burr grinder tailored to the needs of SMEs. Addressing the noise level remains crucial for user-friendly and safe operation in commercial settings.

Data availability statement

Data will be shared upon request by the readers.

CRediT authorship contribution statement

Rofandi Rori Aditiar Warandi: Formal analysis, Writing original draft, Ari Rahayuningtyas: Conceptualization, Methodology, Resources, Investigation, Data curation, Funding acquisition, Writing – review & editing. Maulana Furqon: Writing – original draft, Validation, Data curation, Supervision. Dadang Gandara: Data curation, Taufik Yudhi : Data Curation, Ade Rosadi: Project administration, Data curation, Samsu : Writing – original draft. Santoso: Formal analysis, Investigation. Azis Budi Setyawan : Funding acquisition, Writing – review & editing. Subardiya Noor: laboratory data analysis.

Declaration of Competing Interest

The authors of this manuscript declare no conflict of interest or competing interest.

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