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Innovative Coffee Roasting Machine with Sorting and Packaging System in Alamendah Tourism Village

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ABSTRACT IN ENGLISH

Coffee is one of the agribusiness commodities highly sought after by many MSME players, especially in Bandung Regency, West Java. However, the Assisted Unit of Alamendah Tourism Village faces challenges such as inconsistent coffee quality, unstable roasting temperatures, and low efficiency in sorting and packaging. Through the Student Creativity Program for the Application of Science and Technology (PKM-PI), an Innovative Coffee Roasting Machine with an Automated Sorting and Packaging System was developed using the Design Thinking methodology. The implementation of this innovation increased production from 110 kg to 210 kg per month (a 90% increase). The cooling machine reduced cooling time by 50%, ensuring more consistent coffee bean quality. Automated sorting improved classification accuracy, minimizing product defects. With this innovation, the MSME-scale coffee agribusiness sector has greater opportunities for sustainable growth. This automated sorting and packaging technology also has the potential to be applied on a larger scale, thereby enhancing the competitiveness of the local coffee industry in both national and international markets.

Keywords:
Coffee; Roasting; Sorting-System; Packaging; MSMEs

1. INTRODUCTION

Coffee is one of the agribusiness commodities that has appeal to MSME players today. According to the Central Bureau of Statistics website [1] the amount of coffee production in Indonesia has increased in recent years. Coffee in the country has long been recognized by the Indonesian people so not a few people cultivate coffee bean-producing plants. In total coffee plantation land area, Indonesia has approximately 1,250,452 hectares with details of 1.1% large state plantations, 0.7% large private plantations, and 98.2% smallholder plantations. According to the Central Bureau of Statistics in 2020 [2], One of the coffee producers in Bandung Regency is the Coffee MSME Assisted Unit in Alamendah Tourism Village. This MSME was initially formed in March 2017 as nine separate coffee bean management groups. In April 2023, these groups merged into a single unit to strengthen collaboration, improve production efficiency, and enhance coffee quality. By consolidating resources and expertise, the MSME aims to optimize its operations and meet growing consumer demand.

The Coffee MSME consists of 635 farmers who take care of 1200 hectares of coffee plantations. The coffee farmers will hand over the cherries to be processed into roast beans through the roasting process by the Coffee MSME. MSME Coffee does not have fixed daily activities in roast bean production because it implements a stock-by-order system. Consumers can order 5-100 kg of coffee beans in one month. The roast bean-making process is carried out 2-3 times a week. This process is carried out using a roasting machine with a production time of 32-42 minutes and a packaging time of 20 minutes. In one roasting process, MSME Coffee can produce as much as 1 kg of roast bean. The capital required by MSME Coffee is IDR 2,777,432.32 with a profit of IDR 25,000 per kg in one month. After becoming roast beans, the coffee beans will go through the packaging stage and will be distributed to consumers. MSME Coffee consumers are spread from Bandung City to Yogyakarta City.

Coffee MSMEs in Alamendah Tourism Village have a roasting machine with dimensions of 56 x 35 x 59 cm and a cooling machine with dimensions of 30 x 7 x 10 x 7.5 cm. In the roasting machine, there is a dynamo electricity drum, airflow electricity, and a cooling bin. The power used in each part is 25 W/ 220 V, 30 W/ 220 V, and 44 W/ 220 V. In addition to using power to run the machine, 3 kg LPG gas is needed to assist in the roasting process. However, the cooling machine on the roasting machine owned by MSME Coffee has not worked optimally. This is because the heat distribution on the cooling machine is still uneven and there are coffee bean skins that are still integrated with the roast bean. In addition, the cooling process is still carried out manually using hands and spoons, so the roaster requires more energy and a relatively longer time. Another problem faced by Coffee MSMEs, namely consumers complaining that the color of the maturity level of the coffee beans received is uneven with their orders.

To address these challenges, various studies have explored innovations in coffee roasting and processing to enhance quality and efficiency. Research by Paramida et al. (2022) showed that the use of a roasting system can enhance color uniformity and coffee bean maturity levels by up to 99.23% [3]. Additionally, another study by Almanda et al. (2024) discussed how the performance of a roasting machine equipped with a coffee bean cooling device resulted in an average final moisture content of 0.97%. The cooling process using this device allowed roasted coffee to reach a temperature of 35°C in just 8 minutes, significantly reducing cooling time while maintaining better coffee bean quality and minimizing moisture loss. [4].

However, a research gap exists in the scale of implementation. While these previous studies were conducted in controlled laboratory settings, our research is directly implemented at the MSME level. This real-world application enables the assessment of the technology's practicality, efficiency, and adaptability in an actual business environment, addressing operational challenges that may not be evident in laboratory conditions. To bridge this research gap and enhance the practical application of coffee processing technology at the MSME level, our study focuses on developing innovative solutions tailored to real-world production challenges.

The process of making coffee beans involves many stages [5]. One of the important processes to obtain the aroma and taste of quality coffee is the coffee roasting process [6]. The implementation that the team can propose is a cooling machine that has stirring and cooling features. The stirring and cooling features are set automatically so that the cooling process is more efficient. In addition, the team proposed a sorting system integrated with a conveyor as a sorting tool as well as a roast bean distributor for the packaging process. The sorting system helps in separating coffee beans based on the color of the roast bean maturity level [7]. To improve roast bean quality, the team proposed a packaging tool in the form of a sealer. These innovations aim to optimize their production process, improve efficiency, and enhance the quality of their roasted beans, ultimately supporting the sustainability and competitiveness of their businesses. Therefore, the presence of this roasting machine innovation can increase the profits of Coffee MSMEs, increase worker productivity, and increase customer satisfaction and loyalty to Coffee MSMEs.

2. METHOD

Village development is one form of implementation of the Tri Dharma of Higher Education. One of the activities that align with this practice is PKM (Program Kreativitas Mahasiswa), which was launched by Ditjen Diktiristek in 2023 and is managed by Belmawa. The purpose of PKM activities is to foster, accommodate, and realize students' creative ideas and innovations. The Roast Filling team participated in PKM-PI (Application of Science and Technology) to solve problems faced by Coffee MSMEs in Alamendah Tourism Village through innovative product development.

This research applied the Design Thinking method to understand the needs and challenges of coffee farmers more deeply. The process began with empathizing through discussions and brainstorming sessions with partners to identify problems, such as inconsistencies in roasting quality and productivity limitations. Based on this understanding, the team proceeded to the define stage to specify key issues that needed to be addressed.

To generate solutions, the team conducted ideation sessions focusing on technological innovations, such as an automated sorting and packaging system integrated into the coffee roasting machine. The prototype stage involved designing and creating an initial model of the roasting machine using Autodesk Inventor 2022. The final stage, the test, was carried out by evaluating the prototype directly with coffee farmers to gather feedback and make iterative improvements.

The baseline data used for comparison were collected through offline activities involving observations and interviews with partners, focusing on existing conditions such as roasting duration, water content, and productivity levels. This approach ensured that the product development was user-centered and aligned with the needs of coffee farmers in Alamendah Tourism Village. Content and sorting to improve quality and increase productivity. A chart of the stages of the activity in question, as follows:

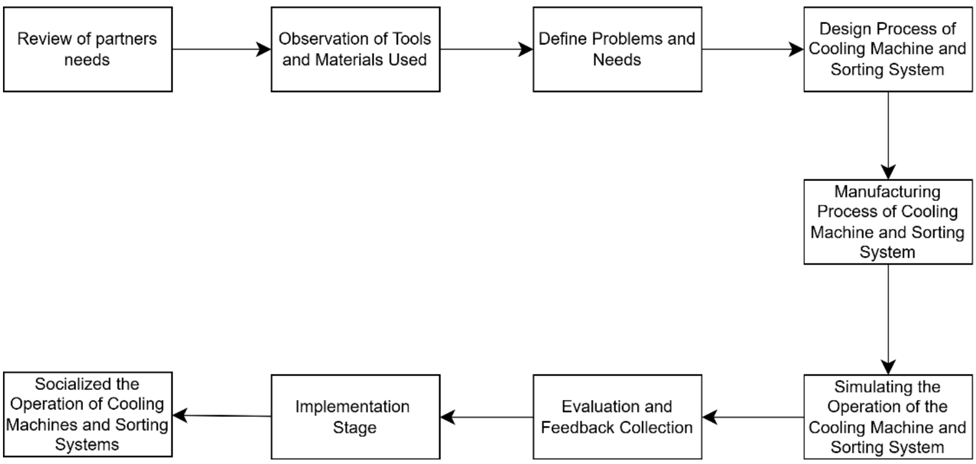

Figure 1 - Base-line activities based on existing partners

To measure the problems owned by the Coffee MSME partners of the Alamendah Tourism Village Fostered Unit in improving the quality of partner coffee beans, several steps can be taken to measure the problem, namely, as follows.

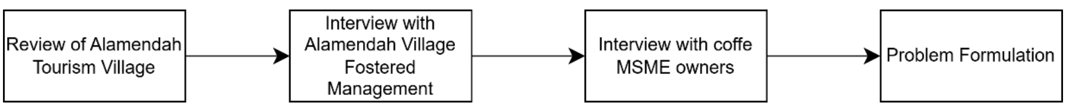

Figure 2 - Steps in measuring the problem

In addition to knowing the conditions of the partners, it is necessary to be strategic in realizing the idea, namely by making the machines needed to improve the quality of coffee beans (roast beans) with criteria tailored to the level of roasting desired by consumers. In realizing the idea, clear and coherent steps are needed.

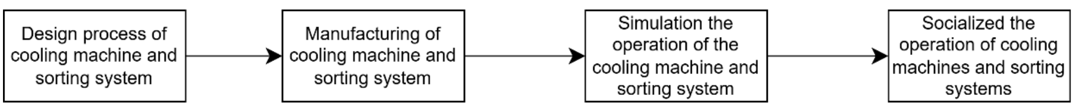

Figure 3 - Step-by-step strategy to realize ideas

After designing a strategy to realize the above ideas, a design is needed to measure the achievements of the activities carried out for partners regarding improving the quality of coffee beans to match the desired roasting level so that sales of coffee beans increase.

The sample chosen is robusta coffee, which is a type of coffee that is often used by partners with a maximum roasting process of 1 kg. To ensure representative results, the study used the purposive sampling method, where only one type of coffee was determined for the study with each weight of 1 kg using a roasting machine, cooling machine, and sorting machine compared to the manual process method. In the testing process, various key parameters are measured to determine the comparison of the coffee roasting process. The parameters measured are as follows.

a. Color, Odor, and Taste Parameters of Coffee

Testing the level of roasting maturity is done by observing each sample of roasting results such as light, medium, and dark by using a sorting system that has been integrated with a conveyor. In the book "Rahasia Candu - Roasting Kopi" by PT NOR Coffee Indonesia [8], the types of roasting are categorized based on colors as follows: Light roast coffee beans have a light brown color. Other characteristics include no oil on the surface of the coffee beans, the beans still appear as clear as they originally were, light roast temperature ranges from 180 °C to 205 °C, and distinctive notes like citrusy, earthy, and buttery. Medium roast coffee beans have a darker brown color, no oil is released on the surface of the beans, and the temperature of the beans ranges from 210 °C to 220 °C, producing coffee that tends to be balanced in aroma, acidity, and has a lot of flavors. Dark roast coffee beans are black with an oily surface, have a significant amount of bitterness, the original coffee flavor is lost while the roasting flavor is very pronounced, and have a temperature of around 240 °C. By observing the sample and detecting the color with a color sensor system that can be known in terms of the color, smell, and taste of each sample. There are standard parameters of color, odor, and taste of coffee based on SNI 8964: 2021 [9].

Table 1 - Coffee Color Parameters Based on SNI 8964: 2021 Source [9]

Parameters	Standard
Color	Uniform
	Sunny
	Grayish-blue and/or grayish green

Table 2 - Coffee Odor Parameters Based on SNI 8964: 2021 Source [9]

Parameters	Standard
Smell	Fresh or no musty odor

Table 3 - Coffee Odor Parameters Based on SNI 8964: 2021 Source [9]

Parameters	Standard
Coffee Flavor	Dominant Coffee Flavor
	Does not cause an annoying aftertaste

Sorting roast beans is one of the processes to determine and separate beans based on color levels using the TCS3200. In principle, color reading on the TCS3200 is done in stages with frequencies based on primary colors simultaneously to filter each primary color [10] This process is the final determinant of the quality and grade of the coffee beans that will eventually be marketed. The sorting components used are a conveyor, Arduino UNO, color sensor, and servo wualnd. TCS3200 sensor with a color receptor that is more sensitive to the color of coffee beans, namely blue. There are coffee bean color standards based on color receptors, as in Table 4.

Table 4 - Color Parameter of Maturity Level Source [11]

Color	Maturity Level		
	Light	Medium	Dark
Blue	27.56 - 35.87	30.00 - 34.46	25.18 - 35.43

b. Parameter Water Content

This water content test is carried out by measuring coffee beans that have been roasted using a water content measuring device known as a "Tester" so that it can determine the percentage of water contained in coffee beans. Also, the coffee beans recommended by SNI are 12.5% based on SNI 8964: 2021 concerning roasted coffee and ground coffee [8]. Each color of the maturity level of coffee beans has a different level of water content.

Table 5 - Water Content Parameters Source [11]

Water Content	Maturity Level		
	Light	Medium	Dark
Percentage (%)	3.98 - 5.51	3.67 - 4.83	1.89 - 4.93

c. Physical Condition Parameters

Testing the physical condition of roasted coffee beans is conducted by observing each sample during the cooling process in both the existing and proposed machines. The evaluation focuses on whether the roasted beans are properly separated from their dry skin or remain mixed, as this factor affects the overall quality and consistency of the final product. By comparing both methods, it becomes evident that the proposed machine, which utilizes an automated cooling system, provides more efficient dry skin separation compared to the manual cooling process in the existing method. Additionally, this improvement ensures that the final roasted beans have a more uniform appearance and reduced contamination from excess dry skin, which is crucial for achieving higher-quality coffee. The findings from this observation highlight the significant impact of cooling technology on the post-roasting process, emphasizing the advantages of automation in improving coffee bean quality.

d. Parameter Cooling Time

Testing for comparison of cooling time on coffee beans (roast beans) is done by observing the time of each sample in the cooling process to prevent further heating from occurring so that it can change the color, *flavor*, volume, or level of maturity of the desired coffee beans (roast bean). For coffee beans cooled using room temperature or ± 27˚C is done for 10 minutes [12] The cooling machine is a component used to cool coffee beans after the roasting process. During this process, the coffee beans will reach very high temperatures and need to be cooled immediately to prevent over-roasting or exceeding the desired color. During the roasting process, there will be a stage of water evaporation at 100 °C and a stage of pyrolysis at 180 °C [13].

3. RESULT AND DISCUSSION

The implementation of roasting machines, sorting systems, and packaging have been implemented by Coffee MSME partners from the Alamendah Tourism Village Assistance Unit. Previously, the production process was carried out manually with conventional methods, which relied on natural cooling and manual sorting of coffee beans. With the proposed use of the machine, the partner experienced an increase in production capacity and consistency in the quality of the roasting results. The analysis used in this study is descriptive, where the data obtained is analyzed without an inferential statistical test. The comparison of production results is based only on direct observation of the production amount before and after the use of the proposed machine.

Table 6 shows the comparison of the amount of coffee bean production at various roasting levels (light, medium, and dark) between the existing production method and the production method using the proposed machine.

Table 6 - Comparison of Coffee Bean Production

Week	Proposal Machine (kg)			Existing Machine (kg)		
	Light	Medium	Dark	Light	Medium	Dark
Week 1	15 kg	25 kg	8 kg	10 kg	15 kg	5 kg
Week 2	20 kg	30 kg	0 kg	10 kg	15 kg	0 kg
Week 3	22 kg	25 kg	5 kg	5 kg	10 kg	5 kg
Week 4	20 kg	35 kg	5 kg	10 kg	20 kg	5 kg

From this data, there is a significant increase in the number of productions every week after the implementation of roasting and sorting machines. Overall, the use of the proposed machine results in higher production than the existing method.

In addition to being displayed in the form of a table, the comparison of the total coffee production between the existing method and the proposed machine is also visualized in the form of a graph in Figure 4. This graph shows the total increase in coffee production after the implementation of roasting machines, sorting systems, and automatic packaging. Based on the graph, the total coffee production with the proposed machine has increased significantly compared to the existing method. Overall, coffee production, which previously only reached 110 kg per month with the manual method, increased to 210 kg per month after the implementation of the machine.

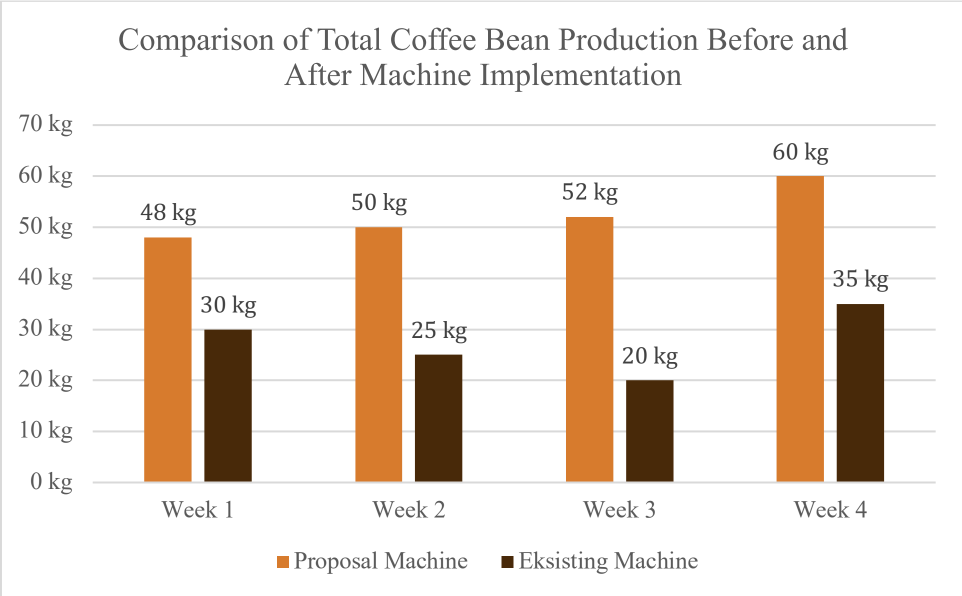

Figure 4 – Comparison of Coffee Bean Production, Before and After Implementation

This increase is due to the efficiency of the roasting and sorting process, which allows for more production in less time. Consistency of roasting results, where sorting coffee beans based on roasting level becomes more accurate. Reduced manual processing time, so partners can produce more coffee without significantly increasing the workload.

a. Technology Design Applied.

In the process of designing a roasting machine design with a sorting and packaging system using Autodesk Inventor software.

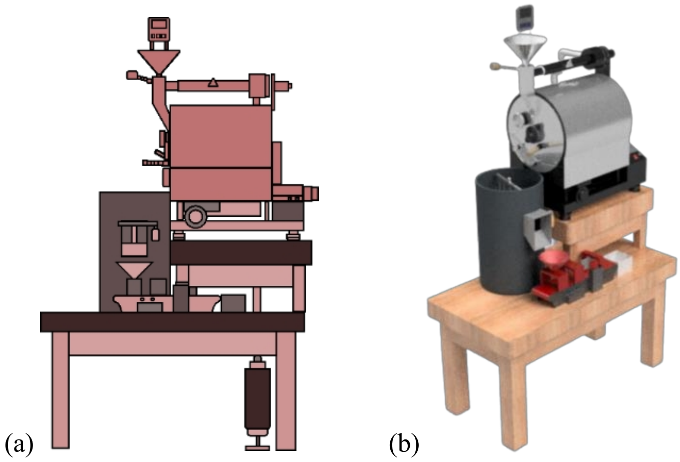

Figure 5 - (a) 2D Design; (b) 3D Design

The results of the roasting machine design with sorting and packaging systems have been adjusted to the needs and desires of partners. In both 2D and 3D designs of the roasting machine, it is necessary to adjust the placement of the roasting machine with the sorting and packaging system following the existing layout conditions in the roasting machine room so that several workstations are needed in one room.

Figure 6 shows a workstation in the coffee roasting production process. Workstation 1 serves as the main stage in the roasting process, where the coffee beans are roasted at a controlled temperature to achieve the optimal level of ripeness. The roasting process of coffee beans is carried out using a roasting machine, after that, the coffee beans are cooled to stop the roasting process and maintain their quality. Furthermore, on workstation 2, Workstation 2 focuses on the sorting process, where the cooled coffee beans are inspected and separated based on the desired quality and color level.

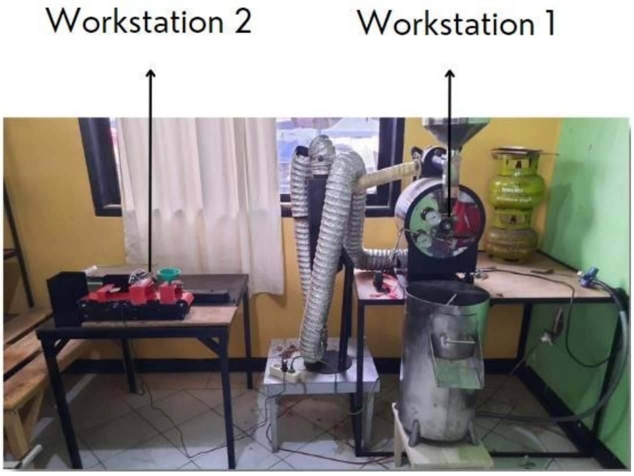

Figure 6 - Proposed Workstation

b. Color, odor, and taste parameters of roast bean

Coffee color, aroma, and taste parameters were evaluated to determine the characteristics of coffee beans, especially in assessing the maturity level of roasted results [14]. Aroma and taste testing is carried out through sensory evaluation by observing several samples. Meanwhile, the color test was carried out using a TCS3200 light sensor, which is more sensitive to the blue color spectrum, which is a key indicator in detecting the roasting rate of coffee beans [15]. The color measurements were concluded based on Table 4. The results of the coffee color, aroma, and taste test can be seen in Table 7 below.

Table 7 - Results of Coffee Color, Odor, and Taste Parameters

Parameters	Maturity Level		
	Light	Medium	Dark
Color Sensor Detection Results	28.56 (Appropriate)	32.13 (Appropriate)	34.27 (Appropriate)
Smell	Normal	Normal	Normal
Taste	Normal	Normal	Normal

c. Moisture content parameter

Moisture content is the water content in coffee beans, measured as a percentage. The water content in coffee beans will affect the quality and flavor of the coffee produced. This test is carried out using the Wile Coffee Moisture Meter tool which is filled using a sample of coffee beans. The test result data using the moisture content parameter can be seen in Table 8 below.

Table 8 - Moisture Content Parameter Results

Parameters	Moisture Content Level		
	Light	Medium	Dark
Results Using Existing Machine	4.2%	4.2%	4.0%
Results Using Proposed Machine	4.2%	4,0%	4,0%

Table 8 of the results of moisture content testing carried out on existing machines and proposed machines did not show significant differences from the three types of maturity and following the recommendations from SNI, the maximum moisture content is 12.5% based on SNI 8964: 2021 so that the moisture content testing of coffee beans using the proposed machine and the existing machine is still fairly safe.

d. Physical condition parameter

Based on tests carried out physically on the coffee beans produced as well as through the proposed machine, it proves that the quality of coffee beans is not mixed with dry skin attached to the residue of the roasting process to produce coffee beans with quality beans, clean, and suitable for consumption by customers. Test result data using the physical condition parameters of coffee beans can be seen in Table 9 below.

Table 9 - Results of Physical Condition Parameters

Parameters	Standard	Existing Machine	Proposed Machine
Physical Condition	Do not mix with dry-skin roast bean	Mixed with dry roast bean skin	Do not mix with dry-skin roast bean

e. Cooling time parameter

The cooling process of coffee beans in production is to stop the roasting reaction and maintain the quality of the final product. In this study, a comparison of cooling time was carried out between the existing method, which uses a manual fan and human labor, and the proposed method, which uses an automatic cooling device with an optimal rotation system to separate the dry skin from the coffee beans.

Based on the measurement results, the use of cooling equipment in the proposed machine results in better cooling time efficiency, which is about 50% faster than the manual method. Faster and even cooling not only improves production efficiency but also reduces the risk of over-roasting due to residual heat on the coffee beans after exiting the roasting machine. The cooling time comparison data between the existing and proposed methods can be seen in Table 10 below.

Table 10 - Results of Physical Condition Parameters

Parameters	Standard	Existing Machine	Proposed Machine
Time Cooling Process	10 minutes	20 minutes	10 minutes

f. Profit Comparison

This profitability analysis aims to identify the differences between existing roasting machines and newly proposed innovative roasting machines. This comparison includes various parameters of operational and maintenance costs, including power consumption, electricity tariffs, labor costs, gas costs, and maintenance costs. By understanding these differences, researchers can see the real impact of the use of new machines on the operational efficiency and overall profitability of Coffee MSMEs in Alamendah Tourism Village.

Table 11 - Machine Operating & Maintenance Costs

Parameters	Proposed Machine	Existing Machine
Roasting Machine Power	135 watt	99 watt
	12.42 kWh/month	9.2 kWh/month
Electricity Tariff	Rp1,352/month	Rp1,352/month
Operating Hours	7.5 jam/day	7.5 jam/day
	92 jam/month	92 jam/month
Electricity Costs	12.42 KwH x Rp 1,352	9.2 KwH x Rp 1,352
	Rp 16,791.84/month	Rp 12,432.32/month
HR Costs	Rp2,000,000/month	Rp2,000,000/month
Gas Costs	Rp165,000/month	Rp165,000/month
Machine Maintenance Cost	Rp50,000/month	Rp600,000/month
Total Cost of Production	Rp2,231,791.84/month	Rp2,777,432.32/month

In Table 11, it is found that from the operational calculation of the proposed machine and the existing machine, the total production cost required by the proposed machine is IDR 2,231,791.84/month less than the existing machine's IDR 2,777,432.32/month. This is because the cost of existing engine maintenance is quite expensive. After all, it requires more maintenance and requires higher costs.

Table 12 - Revenue Using the Machine

Parameters	Proposed Machine	Existing Machine
Roasting Services	Rp 55,000/kg	Rp 55,000/kg
Amount of Roasting	205/kg	100/kg
Gross Revenue	Rp 55,000 x 205 kg	Rp 55,000 x 100 kg
	Rp11,275,000/month	Rp5,500,000/month
Net Income	Rp9,043,208.16/month	Rp2,722,567.68/month
Profit	Rp90,432.08/kg	Rp27,225.68/kg

The profit comparison between the existing roasting machine and the proposed innovative roasting machine shows a significant improvement in the operational efficiency and profitability of Coffee MSMEs in Alamendah Tourism Village. The new machine reduces the total production cost per kg of coffee, including electricity costs, gas costs, labor costs, and maintenance costs, making it more efficient compared to the previous machine. In addition, the use of innovative roasting machines resulted in a higher profit per kg of coffee, which was IDR 90,432/kg compared to IDR 27,225/kg produced by the previous machine. In other words, this new machine increases the profits of Coffee MSMEs by up to 3.6 times.

In addition to cost efficiency and increased profits, the innovative roasting machine also reduces the time required for the roasting and cooling process, allowing for an increase in production volume without a proportional increase in operating costs. All these results show that innovative roasting machines have great potential to improve the operational efficiency and profitability of Coffee MSMEs in Alamendah Tourism Village, as well as have a positive impact on the welfare of the local community.

The results of this study show that the implementation of roasting, sorting, and cooling machines contributes to increasing the productivity of coffee MSMEs. Testimonials from partners highlight some of the key benefits of this proposed roasting machine. According to him, "this new machine significantly improves the production effectiveness of the roasting process making it easier for us to manage our daily operations" Although this roasting machine innovation provides a significant increase in efficiency and profitability for Coffee MSMEs in Alamendah Tourism Village, there are several aspects that still need to be considered. One of the main challenges is the adoption of technology by business actors. The change from conventional roasting methods to innovative machines requires a lot of initial investment, both in terms of machine procurement costs and training for users.

4. CONCLUSION

This research aims to make an Innovative Coffee Roasting Machine with Sorting and Packaging in Alamendah Tourism Village. The results indicate that the total production increased from 110 kg per month (manual method) to 210 kg per month (proposed machine), reflecting an improvement of approximately 90%. Additionally, the implementation of the cooling machine has reduced cooling time by 50% compared to the manual fan method, ensuring more consistent bean quality. The automated sorting process also provides better classification accuracy, minimizing defects and ensuring that coffee beans meet the required standards. Through this technological intervention, coffee MSMEs in Alamendah Tourism Village can optimize their production process, improve efficiency, and enhance the quality of their roasted beans, ultimately supporting the sustainability and competitiveness of their businesses. As a further step in research, this research can be continued by developing integration with IoT or sensors through applications or optimizing energy consumption in the baking and cooling process to be more sustainable and cost-effective.

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