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ANALYSIS OF PERFORMANCE AND ROASTING QUALITY IN A ROTARY CYLINDER-TYPE COFFEE ROASTING MACHINE

Analysis Kinerja dan Kualitas Penyangraian dalam Mesin Penyangrai Kopi Tipe Silinder Putar

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ABSTRACT

The roasting process significantly impacts coffee's aroma and flavor profile, making it crucial in coffee processing. This study developed a rotating drum coffee roasting machine at laboratory scale with 2.0 - 2.5 kg batch capacity. Heat is provided by an LPG-powered pressure cooker burner. The research aimed to evaluate machine performance and assess roasted coffee quality. The roasting process is classified into light, medium, and dark levels. Tests show roasting temperatures from 192°C to 225°C, with times between 12 and 17 min. Moisture content of roasted coffee ranges from 2% to 7%, lower than SNI-7465:2008 standards. The motor requires 23.34 watts of electrical power to operate. Energy consumption for light and medium roasts is 4708.93 kJ, while dark roast needs 9417.86 kJ. Roasted coffee uniformity exceeds 90% at all roasting levels. The weight loss does not exceed 20%. The performance test results indicate the machine's suitability for small-scale coffee industries or laboratories to improve roasting efficiency. Future improvements should focus on better temperature and time control for enhanced flavor profiling.

Keywords: Coffee, Coffee roasting machine, Performance test, Quality Assessment

ABSTRAK

Penyangraian memiliki dampak signifikan pada profil aroma dan rasa kopi, menjadikannya tahap penting pengolahan kopi. Penelitian ini mengembangkan prototipe mesin roasting kopi drum berputar skala laboratorium dengan kapasitas 2,0 - 2,5 kg per batch. Sumber panas disediakan pembakar panci presto bertenaga LPG. Tujuan penelitian adalah mengevaluasi kinerja mesin dan menilai kualitas kopi panggang yang dihasilkan. Proses penyangraian diklasifikasikan menjadi tiga tingkatan: terang, sedang, dan gelap. Hasil pengujian menunjukkan suhu penyangraian berkisar 192°C hingga 225°C, dengan waktu antara 12 dan 17 menit. Kadar air kopi sangrai bervariasi dari 2% hingga 7%, lebih rendah dari standar SNI-7465:2008. Motor membutuhkan daya listrik sekitar 23,34 watt untuk mengoperasikan roaster. Konsumsi energi untuk roast ringan dan sedang adalah 4708,93 kJ, sedangkan dark roast 9417,86 kJ. Keseragaman kopi sangrai melebihi 90% pada ketiga tingkat penyangraian. Penurunan berat kopi sangrai tidak melebihi 20%. Hasil uji kinerja menunjukkan mesin tersebut cocok untuk industri kopi skala kecil atau laboratorium. Perbaikan masa depan harus fokus pada kontrol suhu dan waktu untuk meningkatkan profil rasa.

Kata kunci: Kopi, Mesin penyangrai kopi, Uji kinerja, Asesmen mutu

INTRODUCTION

Coffee is a key plantation commodity that holds a crucial position in Indonesia's economy, alongside oil and gas (Marhaenanto et al., 2015). In 2023, Indonesia is ranked as the fourth largest coffee producer globally, following Brazil, Vietnam, and Colombia. Around 67% of the nation's total coffee production is exported, with the remaining 33% catering to domestic consumption (BPS, 2024). Indonesian coffee exports reach five continents, with major destinations including the United States, Egypt, Germany, and Malaysia. Despite the increasing global market opportunities, the local coffee market also holds significant potential.

The success of coffee agribusiness in Indonesia greatly depends on the synergy of various parties involved in the value chain, from production, processing, to marketing. Efforts to improve productivity and quality are continuously made to ensure Indonesian coffee remains competitive in the global market (Herwidyanto et al., 2023). The application of technology in cultivation and processing, such as selecting superior varieties, plant maintenance, pruning, pest and weed control, proper fertilization, and post-harvest processing, plays a crucial role in producing high-quality coffee. The processing process also plays a critical role in determining the flavor and quality of the final product (Narulita et al., 2014).

The roasting process is one of the most important stages in coffee processing (Mardjan et al., 2022). Coffee flavour can be modified according to consumer preference depending on how the roasting is conducted (Batubara et al., 2019). Roasting is the process of developing the flavor and aroma of coffee beans. There are three levels of roasting: the lowest roast level (light roast) with a roasting temperature of around 193ºC-199ºC, the medium roast level with a roasting temperature of around 204ºC, and the highest roast level (dark roast) with a roasting temperature of 205ºC-220ºC (Paramida et al., 2022). A controlled roasting process is essential for preserving the desired taste and aroma characteristics in coffee beverages (Radi et al., 2021). Key parameters that can be regulated during roasting include time, temperature, and the colour level of the roasted beans (Pakaya et al., 2024).

The development of modern coffee roasting machines has not been matched by affordable prices, especially for home businesses. Currently, many people still use traditional methods of roasting, such as using a wok or frying pan. The downside of this traditional method is that it takes a long time, uses firewood as the heat source, and relies on manual labor. Farmers struggle to achieve even roasting levels (Haslinah et al., 2023). Therefore, to address these limitations, this research analysis focuses on coffee roasting using a coffee roasting machine. Using a machine can overcome the drawbacks of traditional roasting methods because the heat source is controlled, reducing contamination from combustion smoke. To determine the optimal process conditions, an analysis of the coffee roasting process needs to be conducted (Liana et al., 2023).

In general, there are two main methods or types of coffee roasting machines: the rotating drum and fluidized bed types (Putra et al., 2019). Coffee roasted with the rotating drum type is stirred in a rotating cylinder and heated directly. The fluidized bed roasting type uses pressurized hot air to stir and roast the coffee during the process. Heat transfer in this type occurs predominantly through convection, compared to the rotating drum method, which mainly uses conduction (Mulato, 2002). The drawback of the rotating drum type is the difficulty in controlling the roasting temperature, which typically involves high temperatures and long processing times. Additionally, some coffee parchment may remain in the drum, mixed with coffee oil, forming a crust on the drum walls, which can lead to a smoky aroma in subsequent roasts (Paramida et al., 2022).

Previous studies on the performance analysis of coffee bean roasting machines have been widely conducted, one of which is by Batubara et al. (2019), entitled Performance Test and Economic Analysis of Coffee Roasting Machines. The study reported roasting temperatures of 192.4–202.4°C, a moisture content of 3.09%, machine efficiency of 13.30%, power requirement of 126.28 W, roasting yield of 84.2%, fuel consumption of 0.096 kg/hour, ash content of 4.17%, theoretical capacity of 5 kg/process, actual capacity of 0.752 kg/hour, and specific energy of 600.319 kJ/kg; however, it did not include an assessment of the quality of the roasted coffee. Meanwhile, Astuti et al. (2023) found that the fluidized bed roaster significantly reduced moisture content and enhanced antioxidant activity, but the study was limited to Toraja Arabica coffee and did not evaluate the machine's technical performance aspects.

Widodo et al. (2022) demonstrated that a fluidized-bed coffee roaster produced an antioxidant activity of 51%, while the rotary drum type reached 43%, with relatively similar cupping scores of 84.13 and 84.38, respectively; however, this study did not evaluate the machine's technical performance. Meanwhile, Lubis et al. (2023) designed an electric-powered cylindrical coffee roaster equipped with an automatic temperature control system, but the study primarily focused on the design aspect without assessing thermal efficiency or actual performance. Furthermore, the research conducted by Liana et al. (2023) on a 2-kg capacity horizontal drum roaster reported data on power consumption and bean color changes, yet did not address yield, efficiency, or optimal operating time of the machine.

A prototype of a rotary cylinder-type laboratory-scale coffee roasting machine with a capacity of 2–2.5 kg per batch has been developed. The machine is equipped with temperature and time control systems to ensure uniform roast levels. However, the use of this roasting machine remains limited due to the lack of data on its performance and the quality of the roasted coffee it produces. Therefore, this study aims to evaluate the performance of the rotary cylinder-type coffee roasting machine and assess the quality of the roasted coffee. The findings are expected to help identify key modification factors that significantly affect the roasting performance of rotary cylinder-type roasting machines.

MATERIALS AND METHODS

Materials

The raw material used in this study was Robusta coffee beans harvested from coffee plantations located on the slopes of Mount Merapi, Magelang Regency. The coffee beans used had a moisture content of 10% with a tolerance of ±1% and had been sorted to ensure uniform size. A total of 9 kg of coffee beans were used, divided into three replications for each roasting level.

Methods

This study employed a descriptive analysis method by conducting measurements and observations on the performance of the coffee roasting machine and the quality of the roasted coffee produced. The collected data were analyzed to determine the functional feasibility of the machine.

Research Stages

The research process begins with the identification of the problem, where a search is conducted to determine the issue that needs to be addressed, which is how to optimize the coffee roasting process. After the problem is identified, the next step is the literature review of the equipment, where references are gathered regarding the different types of roasting equipment available and their mechanisms. Next, the preparation of tools and materials takes place, ensuring that all the necessary equipment for the experiment is available and ready for use.

In the following stage, equipment performance is tested based on the SNI 7465:2008 (BSN, 2008), where the prepared equipment is evaluated using relevant parameters such as roasting temperature, coffee bean moisture content, roasting rate, process efficiency, power requirements, and energy consumption. Afterward, the quality of the roasted coffee is tested to ensure that the results meet the desired standards. This test includes parameters such as roasting uniformity, color, bean cracking level, coffee bean weight, and density.

Once all tests are completed, an evaluation is conducted to determine whether the results are optimal. If the results are not optimal, modifications will be made to the equipment or the roasting process to improve them. The data obtained from the experiment is then collected and analyzed to identify patterns or significant findings that can help answer the research questions. In the final stage, conclusions are drawn based on the data

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analysis, and if all parameters are met, the process is considered complete.

Performance and Quality Testing Parameters

The performance testing of the coffee roasting machine and the quality testing of the roasted coffee involved several different parameters. The parameters used for performance testing included roasting temperature, moisture content, roasting rate, roasting efficiency, required drive power, and energy consumption. Meanwhile, the parameters used for quality testing of the roasted beans included uniformity, color, crack level, weight, and density.

Coffee Roasting Machine Performance Testing

Roasting Process Temperature

To measure the temperature profile, the increase and decrease in temperature were observed using the temperature indicator on the roasting machine. Temperature changes were recorded at one-minute intervals throughout the roasting process.

Moisture Content of Coffee Beans

According to Indonesian National Standard (SNI) 7465:2008, the moisture content of coffee beans can be determined using the gravimetric method (BSN, 2008). Moisture content as weight loss was calculated using the following equation:

$$M = \left(\frac{m_t - m_d}{m_t}\right) \text{ x } 100\% \qquad (1)$$

Where M is the moisture content of the coffee (%), m_t is the mass of the coffee sample at time t (g), m_d is the mass of the absolute dry coffee sample (g), and t is the drying time.

Roasting Rate

According to Indonesian National Standard (SNI) 7465:2008, the roasting rate can be determined by measuring the initial moisture content and subsequently measuring the moisture content at one-hour intervals from roasted coffee bean samples collected through sampling ports at each location (BSN, 2008). The roasting rate can be calculated using the following equation:

$$\frac{\delta M}{\delta t} = \left(\frac{M_i - M_f}{t}\right) \qquad (2)$$

Where $\frac{\delta M}{\delta t}$ is the roasting rate per hour (%/hour), M_i is the average moisture content of the coffee before roasting (%), M_f is the average moisture content of the coffee after roasting (%), and t is the time required to reduce the moisture content from M_i to M_f (in hours).

Roasting Efficiency

According to Indonesian National Standard (SNI) 7465:2008 roasting efficiency can be calculated using the following equation:

$$\eta\ (\%) = \left(\frac{(M_k \times Cpb\ x\ (T_k - T_i) - tCm_w \times h_{fg})}{Qs}\right) \text{x } 100 \qquad (3)$$

Where η is the roasting efficiency (%), m_k is the mass of the coffee (kg), C_{pb} is the specific heat capacity of coffee (kJ/kg°C), T_k is the final temperature of the coffee (°C), T_i is the temperature at time t (°C), m_w is the mass of the water (kg), h_{fg} is the latent heat of vaporization of water (kJ/kg), and Qs is the total energy input into the roasting system.

Required Driving Power

According to Indonesian National Standard (SNI) 7465:2008 the required driving power can be determined using the following equation:

$$P = \frac{2 \times \pi\ Tn}{60000 \times \eta} \qquad (4)$$

Where P is the power (kW), T is the torque measured during the operation of the drive shaft (Nm), n is the rotational speed of the drive shaft during operation (rpm), and η is the drive system efficiency (%).

Energy Consumption

Energy consumption during the roasting process is calculated by weighing the LPG gas cylinder before and after roasting. The energy requirement from the gas fuel (Ebbg) can be determined using the following equation:

$E_{bbg} = m_{LPG} \times h_{LPG}$ ....(5)

Where E_{bbg} is the energy from the gas fuel (kJ), m_{LPG} is the mass of LPG used (kg) and h_{LPG} is the calorific value of LPG (47,089.288 kJ/kg).

Roasted Coffee Quality Testing

Roasting Uniformity

To analyze the color uniformity of roasted coffee beans, a sampling method was applied by randomly selecting 100 roasted coffee beans. If most of the coffee beans have almost the same color, the roasting result is considered uniform. Conversely, if there is a clear color difference between the coffee beans, the roasting result is considered non-uniform. The percentage of the roasted coffee beans is calculated using the following equation:

$$\text{Roasting uniformity (\%)} = \frac{\text{Number of beans with uniform color}}{\text{Total number of beans}} \times 100 \quad \text{……..(6)}$$

Roast Color

The color of the roasted beans was analyzed using a colorimeter device, which was directed at the coffee beans against a black-colored background. The analysis was based on L* (lightness), a* (green to red), and B* (blue to yellow) values. L* indicates the lightness or darkness of the color, a* represents the green-to-red color range, and B* represents the blue-to-yellow color range. In this study, only the changes in the L value are discussed.

Crack Level of Coffee Beans

The crack level of roasted coffee beans was assessed using a sampling method by randomly selecting 100 roasted beans. The number of cracked beans was recorded and expressed as a percentage. The crack level was evaluated before and after roasting, and the percentage of cracks was calculated using the following formula:

$$\text{Crack Level (\%)} = \frac{\text{Initial crack count}}{\text{Final crack count}} \times 100 \quad \text{……(7)}$$

Coffee Bean Weight

To calculate the weight change, the beans were weighed before roasting (initial weight: 1 kg) and after the roasting process. The weight reduction percentage was calculated using the following equation:

$$\text{Weight Reduction (\%)} = (\text{Initial weight} - \text{Final weight}) \times 100 \quad \text{……..…(8)}$$

Coffee Bean Density

To determine the density of the coffee beans, their volume was first measured. Volume was determined by using a graduated cylinder partially filled with water. Coffee beans were added to the cylinder, and the increase in water level was recorded. The volume of the coffee beans was calculated by subtracting the initial water volume from the final volume. Once the volume was obtained, density was calculated using the following formula:

$$\text{Density} = \frac{\text{Mass (kg)}}{\text{Volume (liters)}} \quad \text{………………….(9)}$$

RESULTS AND DISCUSSION

Description of the Coffee Roasting Machine

The roasting machine to be tested has a roasting capacity of 3 kg per batch. This roasting machine consists of 6 main components: the roasting drum, lid drum, heating unit, control panel, cooling unit, and frame, along with supporting parts such as a dirt collector unit, support wheels, and a roasting level monitoring unit (Figure 1). The drum has a diameter of 0.286 m and a height of 0.300 m, powered by a 0.09 kW electric motor with a gearbox type. The drum rotation speed is 68 rpm. The heat source is a gas burner (LPG).

The gas fuel is supplied from a 3 kg gas cylinder using a ceramic stove with an Infrared Ceramic LPG NG model. Kerosene is supplied from a tank with a pressure of 2 atm. The cooling tank for the roasted coffee beans is vertically cylindrical, with a diameter of 0.30 m and a height of 0.50 m. A centrifugal fan is installed at the bottom of the cooling tank (Figure 1).

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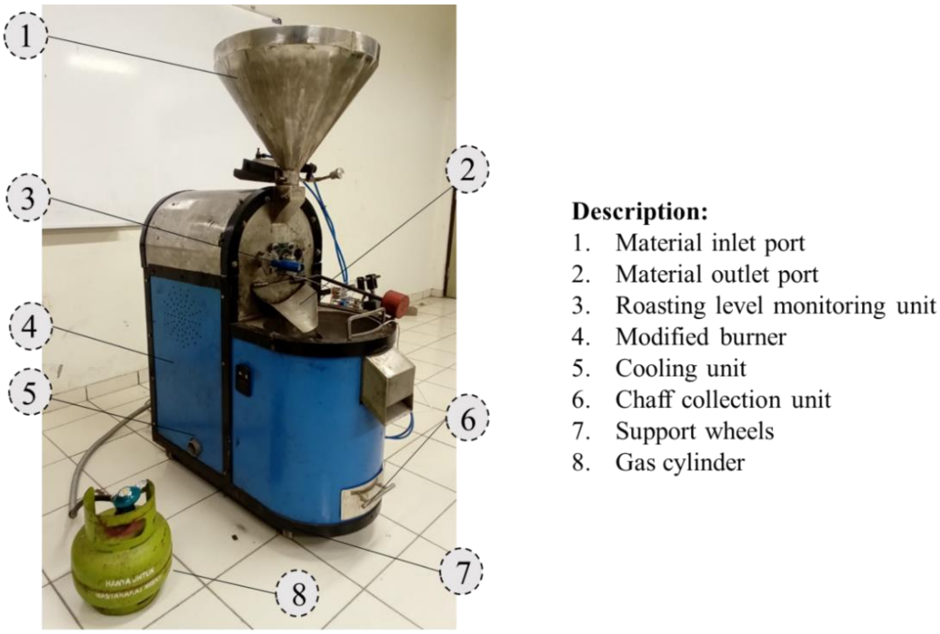

Figure 1. Rotary Cylinder-Type Coffee Roasting Machine

Performance of the Coffee Roasting Machine

To evaluate the performance of the roasting machine, several tests were conducted, including temperature profile, roasting duration, working capacity, moisture content, roasting rate, energy consumption, and required driving power. The purpose of the performance testing is to assess the operational efficiency and functionality of the roasting machine. The results of the performance tests for the coffee roasting machine are presented in Table 1.

Table 1. Performance Test Results of the Coffee Roasting Machine

Parameter	Roast Level		
	Light	Medium	Dark
Input			
Temperature profile (°C)	192	205	225
Roasting time (min.)	12.40	14.49	17.43
Working capacity (kg / h)	4.84	4.14	3.14
Roasting rate (% / h)	25	34	35
Energy consumption (kJ)	4708.93	4708.93	9417.86
Required power (kW)	0.021	0.022	0.027
Output			
Moisture content (%)	7.56	4.53	2.63

Based on the temperature profile measurements during the coffee roasting process, it was found that to reach the light roast color parameter, the temperature increase only reached around 192°C. Next, to achieve the medium roast color level, the temperature rose to around 205°C. For the dark roast color parameter, which requires a longer roasting time, the temperature reached a maximum of around 225°C. This temperature determination aligns with the research of Pramudita et al. (2017), which shows that the roasting temperatures for light, medium, and dark roast are in the ranges of 190°C–200°C, 200°C–220°C, and 220°C–240°C, respectively, according to modern industry standards.

The average time required to roast the coffee beans after placing them in the drum to reach the light, medium, and dark roast color parameters are 12.40 min, 14.49 min, and 17.43 min, respectively. These results match the ideal roasting time standard, which ranges from 10 to 35 min depending on the desired color level. Recent studies indicate that the roast degree (color level) and roasting time are closely related to the flavor characteristics of the coffee, where the darker the desired color, the longer the roasting time required (Münchow et al., 2020). Therefore, it can be concluded that the roasting process is significantly influenced by the color parameters, and the roasting duration increases with the darkness level of the coffee beans.

The actual capacity of the roasting machine is calculated based on the amount of arabica coffee beans produced over a certain period. The calculation of the actual capacity of the coffee roasting machine is done using Equation 9. The results for the actual capacity of the machine for light, medium, and dark roast parameters are 4.84 kg/h, 4.14 kg/h, and 3.14 kg/h, respectively, which are still smaller than the theoretical capacity of the coffee roaster machine at 5 kg/h.

When the machine operates under load, it requires an average power of 0.02334 kW or 23.34 watts. The electric motor used has a power of 180 watts, so the power requirement for the machine can be met by the electric motor. Meanwhile, the fuel consumption during roasting with light and medium roast levels averages 0.1 kg of LPG gas from the initial weight. For the dark roast level, the average consumption is 0.2 kg of LPG gas from the initial weight. The calculated fuel energy (Ebbg) required for each roasting of 1 kg of coffee beans is 4708.93 kJ for light and medium roasts, while for dark roast, it is 9417.86 kJ. Based on the above calculations, it can be concluded that the longer the roasting process, the more energy is required.

The output of the roasting process is roasted coffee with varying moisture content depending on the roast level. Based on measurements, the moisture content of the coffee beans before roasting is on average 9.69%. After roasting, the moisture content decreases to 7.56% for light roast, 4.52% for medium roast, and 2.63% for dark roast. This decrease in moisture content is consistent with the quality standards set by SNI 7465:2008, which specifies that the maximum moisture content of roasted coffee ranges from 1.5% to 5.0%, depending on the roast type and final product quality. Thus, the longer and darker the roasting process, the lower the moisture content in the coffee beans, in accordance with the national quality standards.

Roasted Coffee Quality

To test the performance of the roasting machine, several tests are conducted, including the uniformity of the roasted coffee beans, the color of the roasted beans, the cracking level of the beans, the weight of the coffee beans, and the density of the coffee beans. The results of the quality tests of the roasted coffee can be seen in Table 2.

Table 2. Quality Test Results of Roasted Coffee

Parameter	Roast Level		
	Light	Medium	Dark
Uniformity of Roasting Result (%)	91.11	94.11	97.44
Cracking Level of Beans (%)	11	33	83
Weight (g)	861	832	792
Density (kg/L)	0.53	0.42	0.32

Based on the calculation results, it can be seen that for the light roast color parameter, the average uniformity level is 91.11%, followed by 94.11% for the medium roast, and 97.44% for the dark roast color parameter. The uniformity level of the light roast is the lowest because roasting coffee at the light roast level does not require a long time, so the roasting process may result in unevenness. On the other hand, the dark roast has the highest uniformity level because the roasting time is longer, leading to a more even roasting result. It can be concluded that the longer the roasting process and the darker the desired color parameter, the more uniform the color of the roasted coffee beans will be.

The initial cracking level of the green beans is on average 5%. After the roasting process, the cracking levels of the coffee beans for the light, medium, and dark roast parameters are 11%, 33%, and 83%, respectively. The light roast has the lowest cracking level because its roasting time is the shortest and only goes through the first crack. Meanwhile, the dark roast has the highest

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cracking level because it undergoes roasting until it passes the second crack and has the longest time. Based on this data, it can be concluded that the longer the coffee roasting process, the higher the cracking level.

The weight reduction of the coffee beans after the roasting process shows that the higher the roast level, the greater the weight loss. From an initial weight of 1000 g, the light roast coffee beans average 861 g, medium roast beans 832 g, and dark roast beans 792 g. The weight reduction for each is 139 g, 168 g, and 208 g. This result is in line with the research of Yuniar et al., (2025), which states that the roasting process causes water evaporation and physical changes in the coffee beans, leading to a weight decrease as roasting temperature and duration increase.

The density of the green coffee beans is recorded at 0.72 kg/L. After the roasting process, the density decreases to 0.53 kg/l for the light roast, 0.42 kg/L for the medium roast, and 0.32 kg/L for the dark roast. This decrease in density is caused by the increase in volume due to the expansion of the coffee beans during heating, while mass decreases due to the loss of moisture and volatile compounds. These findings are consistent with the research of Bastian et al. (2021) regarding the physical property changes of coffee beans during roasting. The longer the roasting process and the darker the roast level, the more the volume of the coffee beans increases, while the density decreases significantly.

One of the factors that influence consumer acceptance of a product is color. Figure 2 shows the color measurement results for coffee with light, medium, and dark roasting levels. The L* values are 10.59, 9.50, and 7.53, respectively. The roasting level significantly affects the lightness. The L* value (brightness) tends to decrease as the roasting level increases. This result is consistent with the study by Yeager et al. (2022) on the effect of roasting levels. Increasing the roasting level leads to a decrease in the L* value. According to Saloko et al. (2019), the L* value will be lower with higher temperatures and longer roasting times. The color change occurs due to the Maillard reaction, which is triggered by the combination of temperature and roasting time. The Maillard reaction produces melanoidins, which are characterized by the dark brown color change in roasted coffee beans, resulting in a decrease in the L* value of the roasted beans.

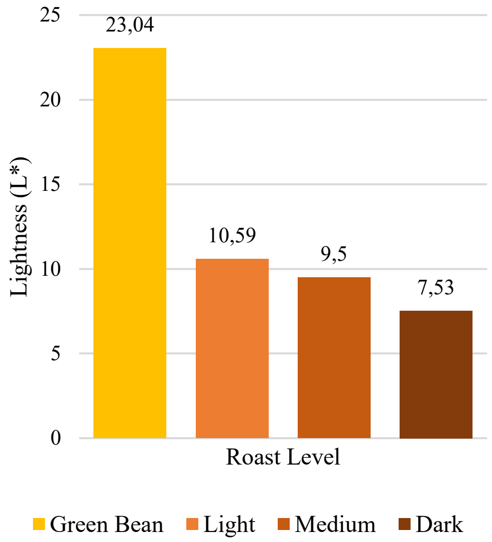

Figure 2. Lightness (L*) of green beans, light roast, medium roast, and dark roast coffee

CONCLUSSIONS

Based on the research results, it can be concluded that the performance test of the coffee roasting machine shows that the machine is suitable for use, as the test parameters meet the requirements of SNI 7465:2008, and the quality of the roasted coffee is good. The test results indicate that the roasting temperature can be adjusted between 192-225°C. The roasting time ranges from 12 to 17 minutes. The moisture content of the roasted coffee is between 2-7%, much lower than the value set by SNI 7465:2008. The electrical power required to operate the electric motor during roasting is approximately ± 23.34 watts. The energy consumption for light and medium roast levels is 4708.93 kJ, while for the dark roast parameter, it is 9417.86 kJ. The uniformity of the roasted coffee produced is already quite good at all three roast levels, >90%. The weight of the roasted coffee decreases by a maximum of only 20%. In general, this machine can be adopted to improve the efficiency of the roasting process at both the laboratory and small industrial levels.

However, further development is needed, including improving temperature control and more precise timing to achieve a more optimal flavor profile according to consumer preferences.

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