

Research Article

The Effect of Chimney Height Variation on the Performance of a Solar-Powered Cascara Coffee Dryer Prototype

Faisal*, Suryadi, Irhamna Ikhwan, Muhammad Sayuthi, M. Iqbal Adhya Putra

Mechanical Engineering Study Program, Faculty of Engineering, Universitas Malikussaleh, Aceh Utara, Indonesia

*Corresponding Author: faisal.tm@unimal.ac.id | Phone: +62-8126936985

ABSTRACT

This study aims to evaluate the effect of chimney height variation on the performance of a solar-powered cascara coffee dryer prototype. Chimney height is an important parameter in drying systems because it affects the rate of hot air flow, relative humidity, and drying process efficiency. An experimental study was conducted by varying the chimney height in the dryer's air outlet duct, then observing the drying performance of coffee cherry husks (cascara) as the test material. The main parameters analyzed included drying time, temperature stability in the drying chamber, drying efficiency, and final product quality. The results showed that variations in chimney height had a significant effect on system performance. A chimney with a height of 220 cm proved to produce the best performance with a more stable air flow rate, consistent drying temperature, and 100% efficiency. This results in a faster, more even, and higher quality cascara drying process. The final product, dried cascara coffee, can then be processed into high-value herbal tea drinks and has the potential to increase coffee product diversification. Thus, this study confirms that proper chimney height adjustment is a crucial factor in the design and development of solar drying technology, especially for agricultural products such as coffee cherry skin. These findings are expected to serve as the basis for developing more efficient, environmentally friendly dryer designs that support increased added value for coffee derivative products at both the farmer and small-to-medium industry levels.

Keywords: Cascara Coffee Dryer; Solar Power; Chimney Height; Drying Efficiency

1. INTRODUCTION

Coffee is one of the plantation commodities that contributes significantly to Indonesia's economy. In addition to serving as a source of foreign exchange and income for farmers, coffee is also an important raw material for industry and creates many jobs (Furqon et al., 2019). Most of Indonesia's coffee production is dominated by the robusta variety, which accounts for 75.4%. This makes Indonesia one of the largest coffee producers and exporters in the world, after Brazil, Vietnam, and Colombia (Indonesian Coffee Plantation Statistics, 2017).

The coffee processing produces waste, mainly coffee husks and pulp, with husks accounting for 40-45% of the total. This waste contains various compounds that have potential for utilization, one of which is coffee husks that can be processed into coffee husk tea or cascara. Although cascara is already known in the international market, Indonesian people's interest in this product is still relatively low. To produce high-quality cascara, an effective drying process is very important to prevent decay. One method that is often used is a solar dryer, which is environmentally friendly. However, drying with a solar dryer is often hampered by the long time required. The purpose of this study is to examine the effect of chimney height variation in solar dryers on cascara drying performance. By utilizing the chimney effect, it is hoped that the drying process can be accelerated, thereby improving the quality of the cascara produced.

1.1 Solar Dryer

Drying is described as an operating system that removes water content thermally to produce products that have low water content and tend to be solid (Abueluor et al., 2023). When solids undergo the drying process, two types of processes occur simultaneously, namely energy transfer and moisture transfer. Energy transfer converts a certain amount of energy into another form (mostly heat energy) from the surrounding environment to evaporate water vapor from the surface (Harrison et al., 2023). Moisture transfer occurs through an internal process from the inside of the product to the surface and from the surface to the surrounding air. The design of the solar dryer prototype can be seen in [Figure 1](#).

1.2 Chimney

A chimney is a vertical ventilation duct installed in a building. Chimneys work based on the principle of natural convection, which is the upward flow of hot air that occurs due to the difference in density between the hot air inside the chimney and the cold air outside. Bernoulli and Archimedes explain the basis of this pressure difference, whereby lighter hot air rises and creates a natural suction that pushes cold air in to replace the rising air, expelling hot steam, hot exhaust gases or smoke produced by stoves, boilers, furnaces, or even fireplaces into the atmosphere (Faisal et al., 2018).

The stack effect is a phenomenon that occurs in chimneys, where the temperature difference between the bottom and top of the chimney creates an upward air flow. This is the basis of the natural chimney draft mechanism that uses gravity to move air. In this study, the function of the chimney itself is to draw air out of the drying process, which will become the air flow in the solar dryer towards a wider area. The height of the chimney affects the efficiency of solar drying. The height of the chimney is the vertical distance measured from the base of the solar dryer to the top of the chimney (Faisal, et al., 2018). Thus, the height of the chimney is measured from the lowest point of the solar dryer.

The chimney is designed with a vertical shape intended to remove humid air upwards, with a height of 220-320 cm. The height of the chimney is measured from the air inlet to the top of the chimney. There are three design variations, with the only difference being the height of the air chimney.

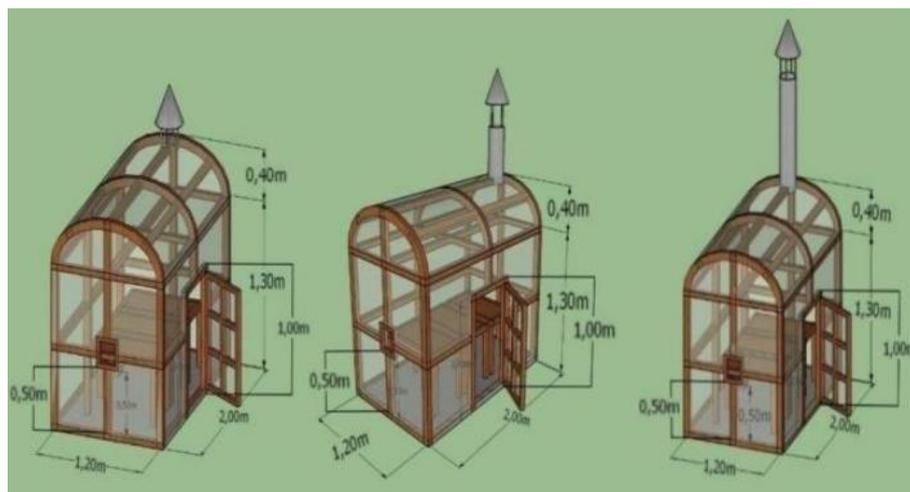


Figure 1. Three Design Variations

1.3 Drying Rate

The duration of the drying process depends on the material being dried and the heating method used. The evaporation of water in the material occurs in three stages, namely: preheating or temperature adjustment of the material being dried, drying at a constant rate (Constant Rate Period), and drying at a decreasing rate (Falling Rate Period) (Treyball, 1983). The drying rate is measured to determine the effect of the drying speed/rate on the solar dryer testing process with different chimney heights. This is done by weighing the initial mass of the product and the final mass of the dried product, then calculating the drying time. To calculate the drying rate, equation 1 can be used.

$$r = \frac{m_1 - m_2}{t_p} \text{ (kg/minute)} \quad (1)$$

1.4 Drying Efficiency

According to Brooker et al., dryer efficiency depends on the temperature of the air entering and leaving the dryer, as well as the relative humidity of the air. They developed a thermodynamic model that explains how efficiency decreases when the air temperature used is too high, resulting in energy waste. Their main focus is on the efficient use of heat, ensuring that only the amount of heat needed to evaporate the water is applied. Henderson and Perry provide an approach oriented towards the agricultural industry, emphasizing drying efficiency in relation to product quality. According to them, drying efficiency is not only measured by energy use, but also by how well the material retains its natural properties (e.g., color, flavor, nutrients) during the drying process. They suggest that drying too quickly can damage quality, so efficiency is also related to the balance between drying speed and final product quality.

The efficiency of a solar drying system can be evaluated based on thermal performance or product drying rate. The thermal efficiency of a solar dryer can be defined as the thermal energy used for drying divided by the available thermal

energy. Efficiency for drying is calculated using equation 2.

$$\eta_{th} = \frac{p_p}{Q_c} \cdot 100\% \quad (2)$$

If is the energy required to evaporate water from the outer skin of coffee beans, then it can be seen in the equation 3.

$$p_p = m_w h_{fg} \text{ (Watt)} \quad (3)$$

If is the heat received by the drying surface (Watts), then it can be expressed as the equation 4.

$$Q_c = I_g \times A_p \text{ (Watt)} \quad (4)$$

Where I_g is the solar radiation that hits the drying surfac (A_p). I_g (Watt/m²) is obtained from measurements using a pyranometer or luxmeter.

2. RESEARCH METHOD

2.1 Research location and time

The research was conducted to determine the differences in the drying speed of cascara coffee in various solar dryer designs, which was carried out in the open field laboratory at Malikussaleh University. Organoleptic testing was conducted using the services of a cupper team at the Redelong Vocational Training Center, Bener Meriah. The color test of cascara coffee was conducted at the Mechanical Engineering Laboratory of Malikussaleh University. The raw materials for the research were taken from a cherry coffee processing facility in Bener Meriah. This research lasted for six months, beginning with a literature study and field survey until the final meeting.

2.2 Tools and Materials

The tools and materials used in this study are as follows:

- Solar Dryer Home
- Spoon
- Wet/dry thermometer
- Spoon
- Digital scale
- Luxmeter/pyranometer
- Digital scale
- Luxmeter/pyranometer

The raw material used was the outer skin of Arabica red coffee beans obtained from coffee bean grinding, which was the waste from the grinding process taken from the coffee processing facility in Weh Tenang Village, Permata Subdistrict, Bener Meriah Regency, Aceh.

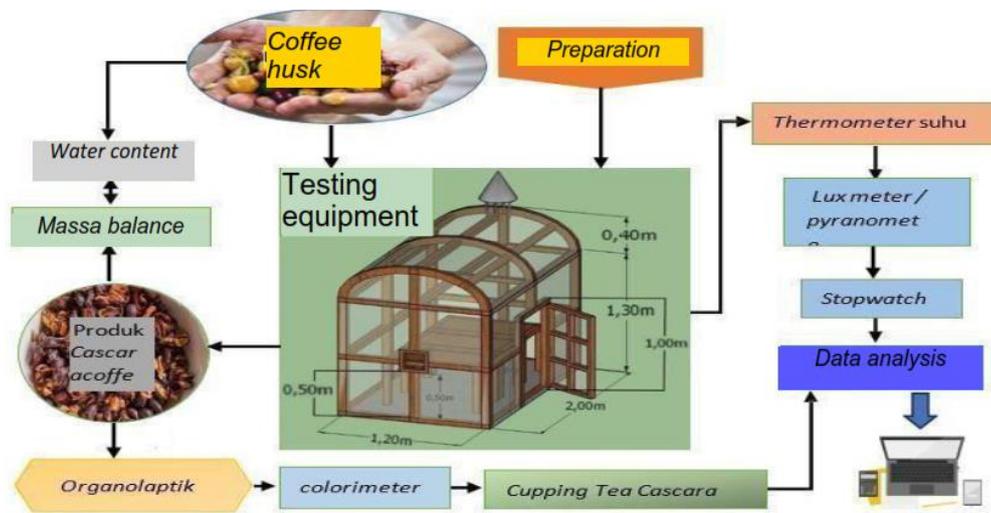


Figure 2. Cascara drying testing process sequence

2.3 Research design

The cascade drying test process can be seen in Figure The research involved a simple drying method with three variations in chimney height, namely 220 cm, 270 cm, and 320 cm. The results of the measurements of the test parameters were analyzed using Statistical Product and Service Solutions (SPSS) software version 29. The research design can be seen in **Figure 2**.

The variables observed in this study are as follows:

1. Independent Variables

- a. Drying speed efficiency of the three variations
- b. Solar dryer
- c. Quality of the resulting product

2. Dependent Variables

- a. Temperature during the drying process
- b. Drying time.

3. Constant Variables

- a. Three variations of solar dryer designs.
- b. The raw material used is coffee bean husks (constant moisture content).
- c. Constant air inlet temperature.
- d. Mini or prototype solar dryer size.
- e. Testing was conducted with a mass of 14 kg.

3. RESULTS AND DISCUSSION

3.1 Environmental Data

Environmental data includes ambient air temperature and humidity, as well as sunlight intensity. Ambient temperature is the dry bulb temperature outside the solar dryer. Data from measurements of ambient air temperature and humidity, as well as sunlight intensity during testing of the dryer without raw materials, is shown in **Figures 3, 4, 5, and 6**.

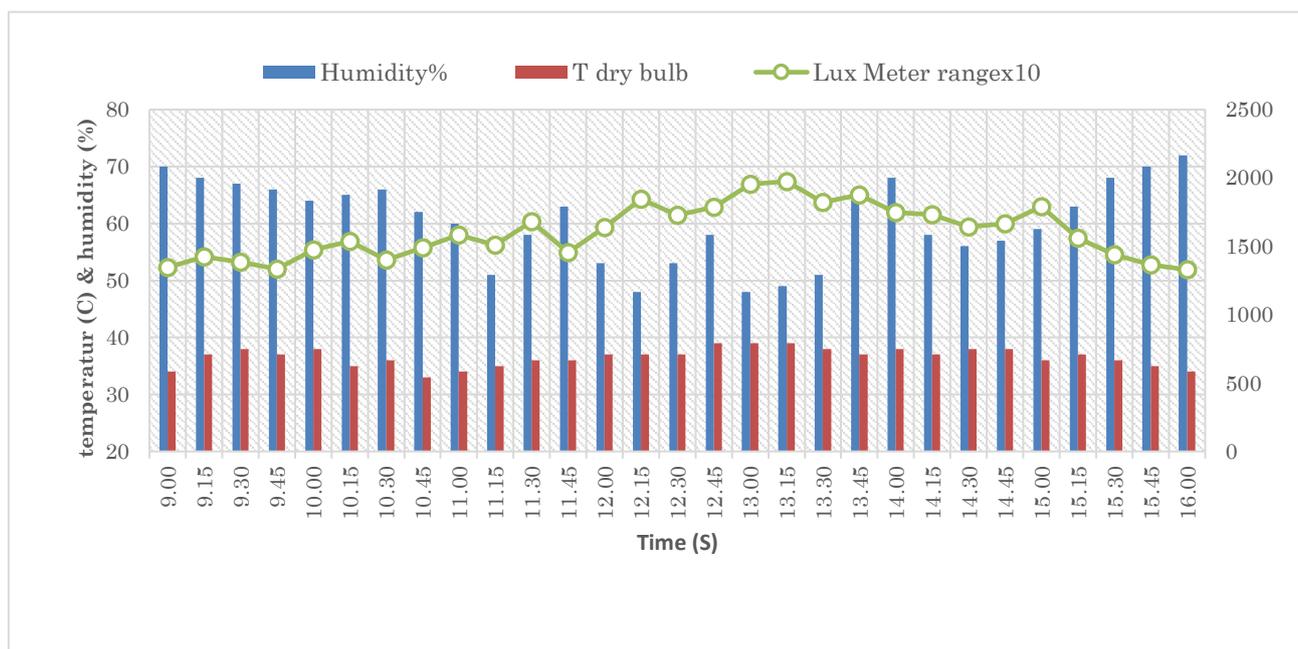


Figure 4. Test results without raw materials

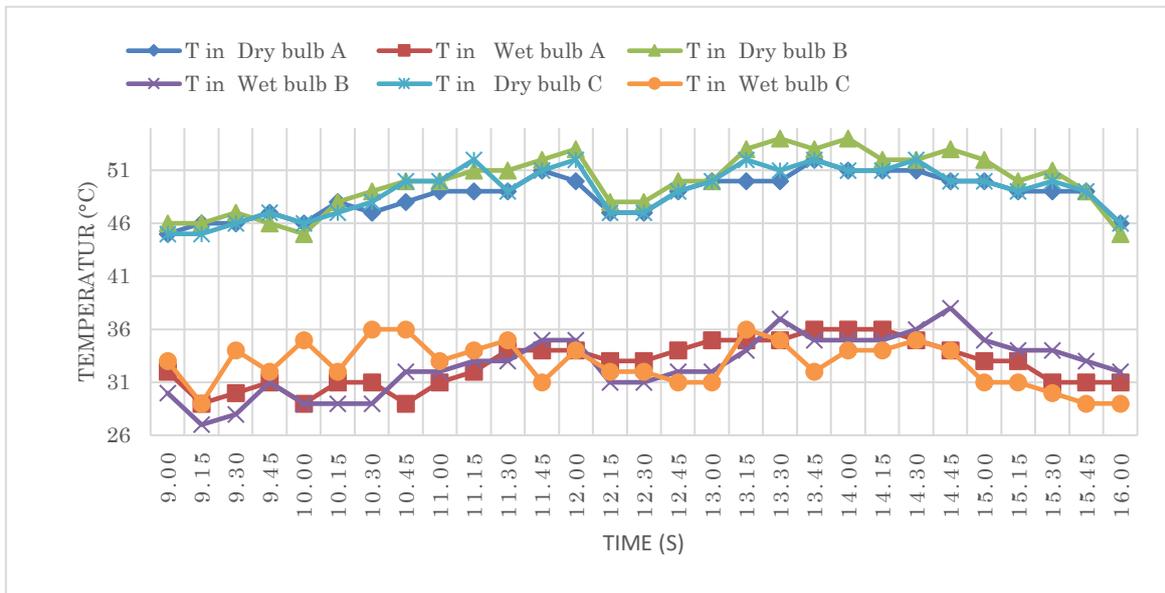


Figure 5. Shows the results of testing the dry bulb and wet bulb air temperatures without raw materials.

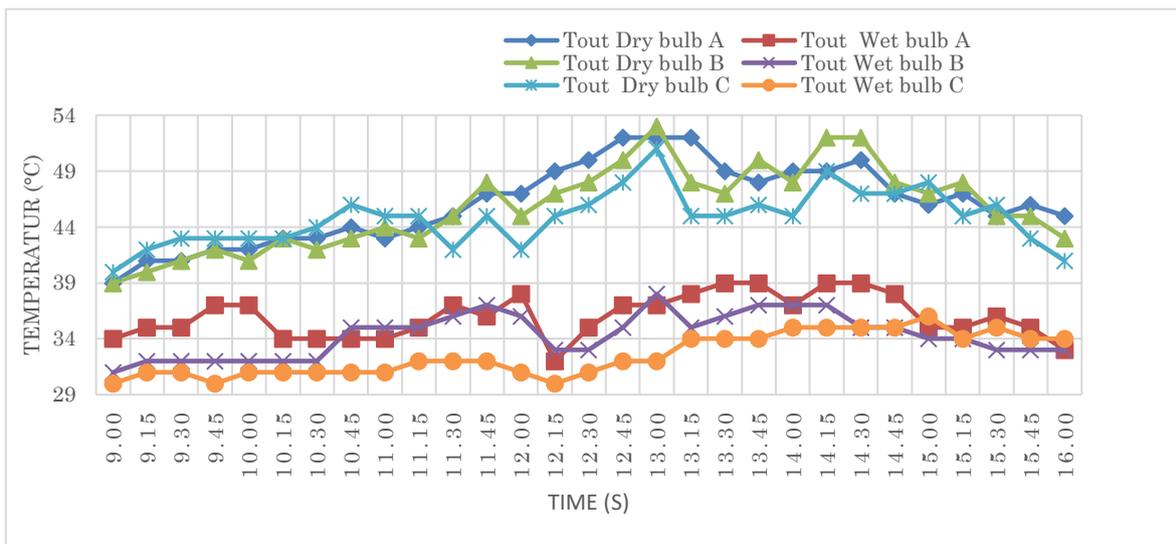


Figure 6. Shows the results of testing the dry bulb and wet bulb air temperatures without raw materials.

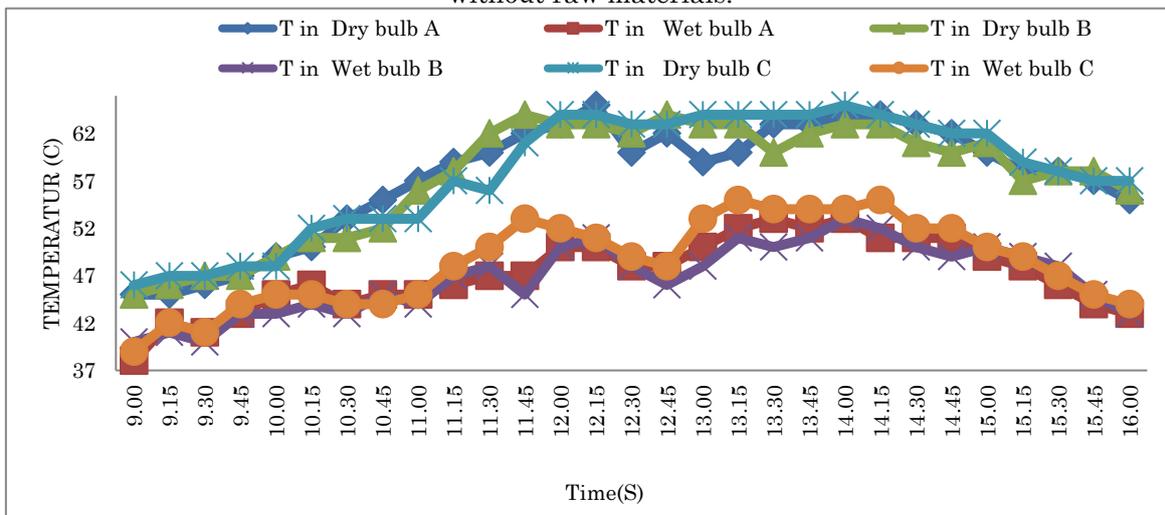


Figure 7. Shows the results of testing the air temperature in dry bulb and wet bulb without raw materials.

3.2 Solar dryer air distribution

The air distribution system of the solar dryer brings air through the air inlet into all chambers of the solar dryer and simultaneously removes all moist air (vapor) and odors from the drying chamber through the chimney air outlet.

a. Thermometer dry bulb data and wet wulb without raw materials

Graph of test results without raw materials for the three types of dryers, A, B, and C. Data from measurements of ambient air temperature and humidity, as well as sunlight intensity during testing of the dryer with 14 kg of raw material for two days each, can be used to create graphs of the distribution of temperature, humidity, and sunlight intensity over time, as shown in **Figures 8**, and **9**.

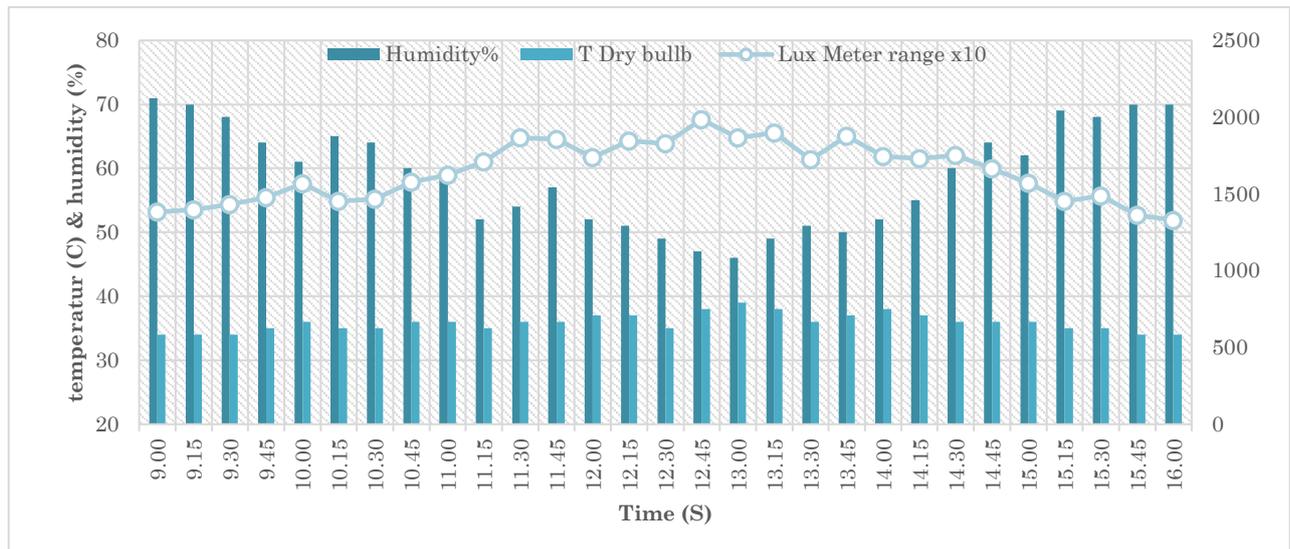


Figure 8. Shows the standard result of 14 kg on the second day.

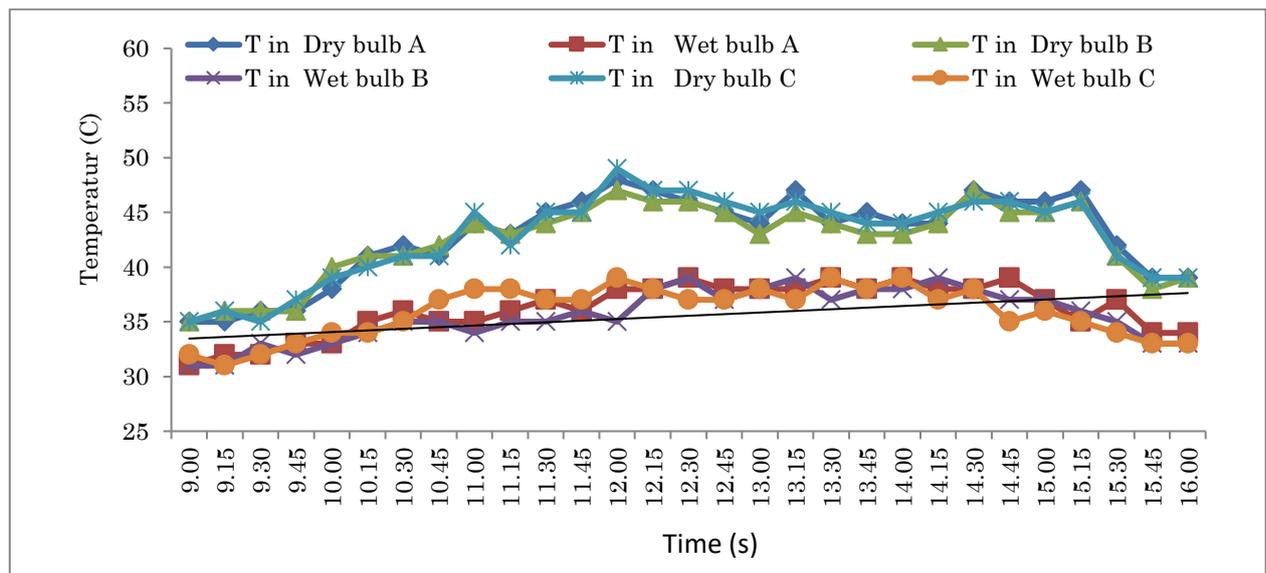


Figure 9. Results of testing the dry bulb and wet bulb air temperatures of 14 kg of raw materials on the first day

3.2 Product moisture content

The drying process involves evaporating water vapor from the outer skin of the coffee beans using air at a higher temperature and low relative humidity. Graphs showing the drying results in terms of product moisture content for 14 kg of raw material on the first and second days can be seen in **Figures 10** and **11**.

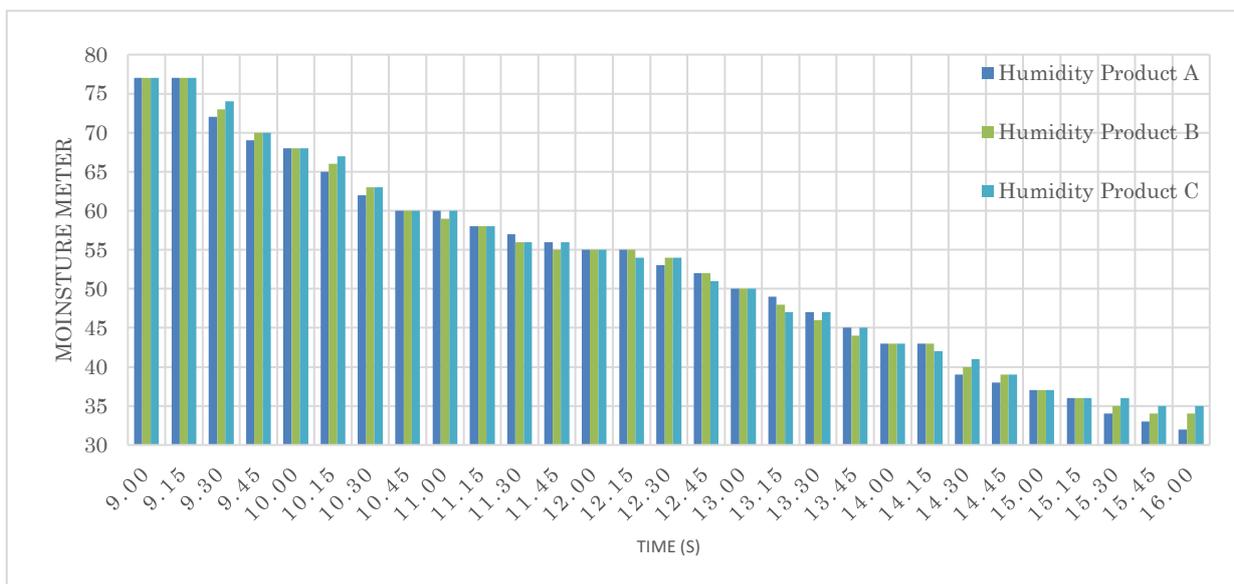


Figure 10. Decrease in moisture content of 14 kg of raw material on the first day.

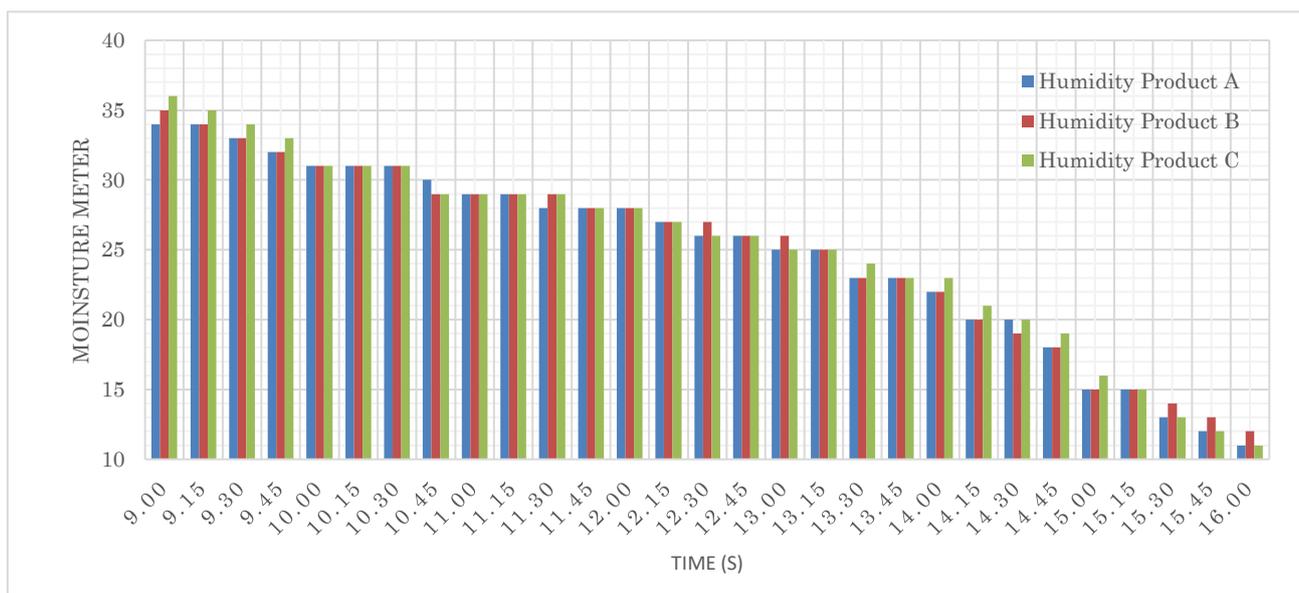


Figure 11. Decrease in moisture content of 14 kg of raw material on the second day.

3.3 Massa Produk

Drying of coffee bean raw materials using 14 kg of raw materials.

a. Massa 14 kg

The third test lasted for two days. The initial mass of raw materials on the first day of the third test was 14.2 kg in dryer A and dryer C, while in dryer B it was 14.3 kg. The mass of raw materials in the afternoon at 16:00 was 7 kg in dryer A, 7.5 kg in dryer B, and 6.9 kg in dryer C. The second day of testing continued with the same raw materials. The final mass of raw material in dryer B was 2.9 kg, while in dryers A and C it was 2.7 kg. Raw material with a mass of 14 kg for 14 hours (two days) was able to shrink by 11.5 kg in dryers A and C, and by 11.4 kg in dryer B. The test results show that the 14 kg raw material mass in dryers A, B, and C only had a slight difference. The graph of the 14 kg raw material mass test results can be seen in Figure 12.

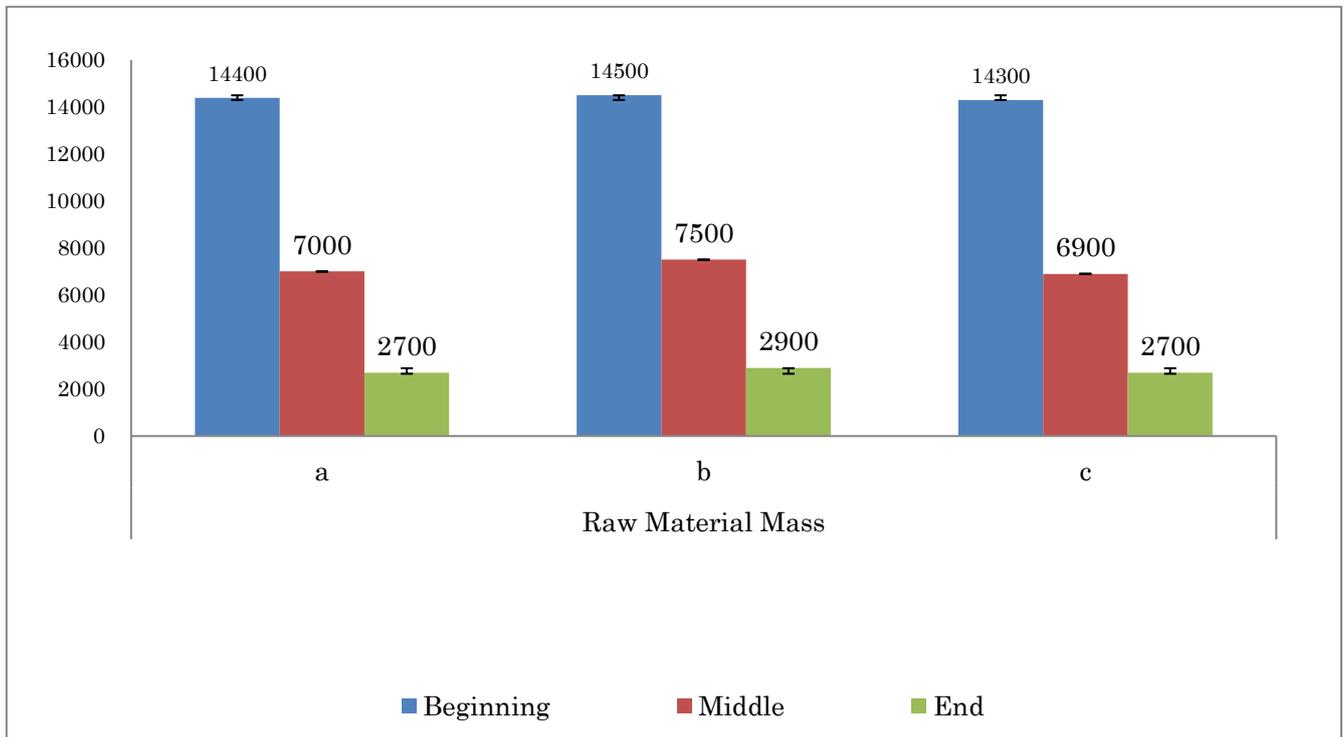


Figure 12. The results of testing 14 kg of raw material

b. Product yield

The final product yield was lower in dryer C with a chimney height of 320 cm, with a yield value of 48.25%. Second was dryer B with a yield value of 48.61%, and third was dryer C with 51.72%. Graph of raw material mass yield for 14 kg on the first day. The final product yield was lower in dryer A with a chimney height of 220 cm, with a yield value of 38.57%. Second was dryer B with a yield value of 38.66% and third was dryer 0C with 39.13%. The final product yield was lower in dryer A with a chimney height of 220 cm, which had a yield value of 18.75%. Second was dryer 0C with a yield value of 18.88%, and third was dryer with a yield value of 20%. The yield graph for 14 kg of raw material on the second day can be seen in Figure 13.

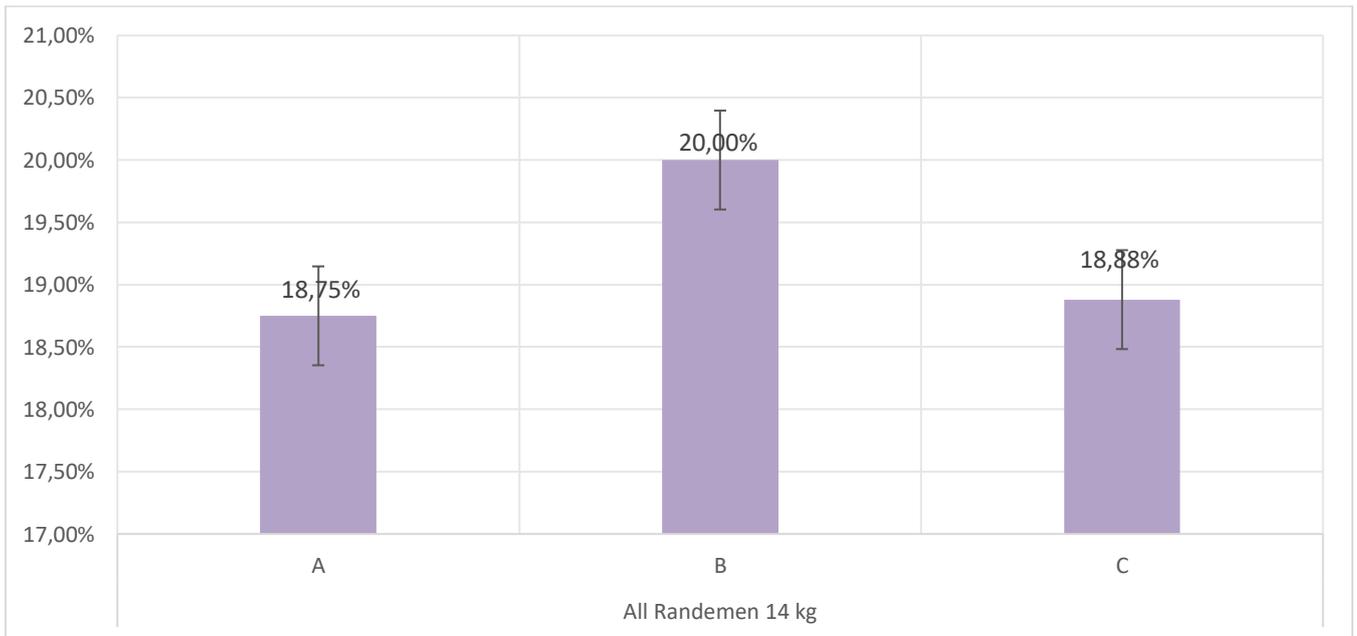


Figure 13. The yield of 14 kg of raw material on the second day

3.4. Average values for humidity, temperature, and lux meter

The first test in an environment without raw materials or in an empty state had an average value of 59% for air humidity, a dry environment temperature of 36°C, and a sunlight intensity of 1583 lux. The second test in an environment with 14 kg of raw materials on the first day had an average value of 61% for air humidity, a dry ambient temperature of 37°C, and a sunlight intensity of 1604 Lux. The second test in an environment with 14 kg of raw material on the second day had an average value of 59% for air humidity, a dry ambient temperature of 36°C, and a sunlight intensity of 1643 Lux, as shown in **Figure 14**.

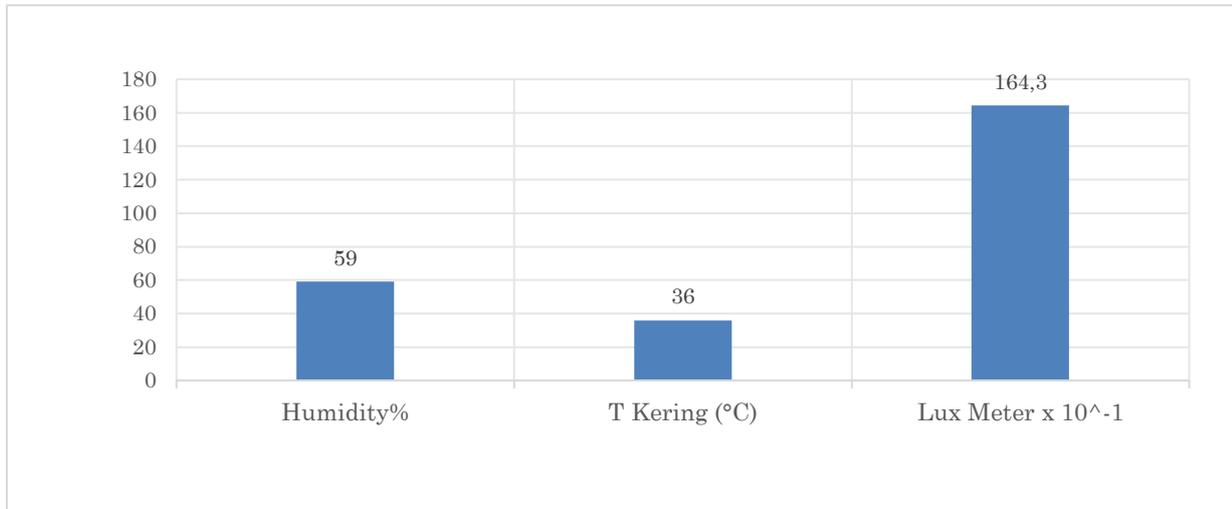


Figure 14. The average mass value of 14 kg on the second day

3.5. Drying rate

The effect of chimney height variation on the drying rate (kg/min) for 14 kg of raw material. For a load of 14 kg, the drying rate is relatively constant, fluctuating only slightly from 13.93 kg/min at point A to 13.81 kg/min at points B and C. This shows that at heavier loads (14 kg), variations in chimney height have a smaller impact on the drying rate, where the decrease in drying rate is more significant. The drying rate graph can be seen in **Figure 15**.

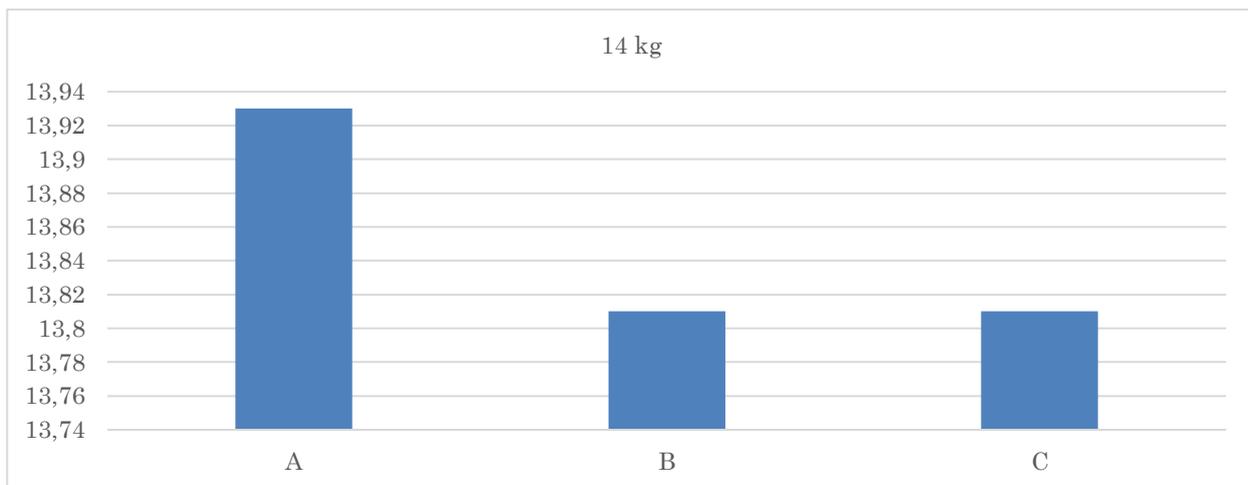


Figure 15. Effect of chimney height variation on drying rate based on raw material mass

3.6. The efficiency

The efficiency of coffee bean dryers for variations in chimney height with a raw material mass of 14 kg, using three types of dryers (A, B, and C). A load of 14 kg on dryers A, B, and C had a relatively constant efficiency of 0.32%. It can be concluded that the effect of chimney height variation did not affect the efficiency between dryers. The efficiency graph can be seen in **Figure 16**.

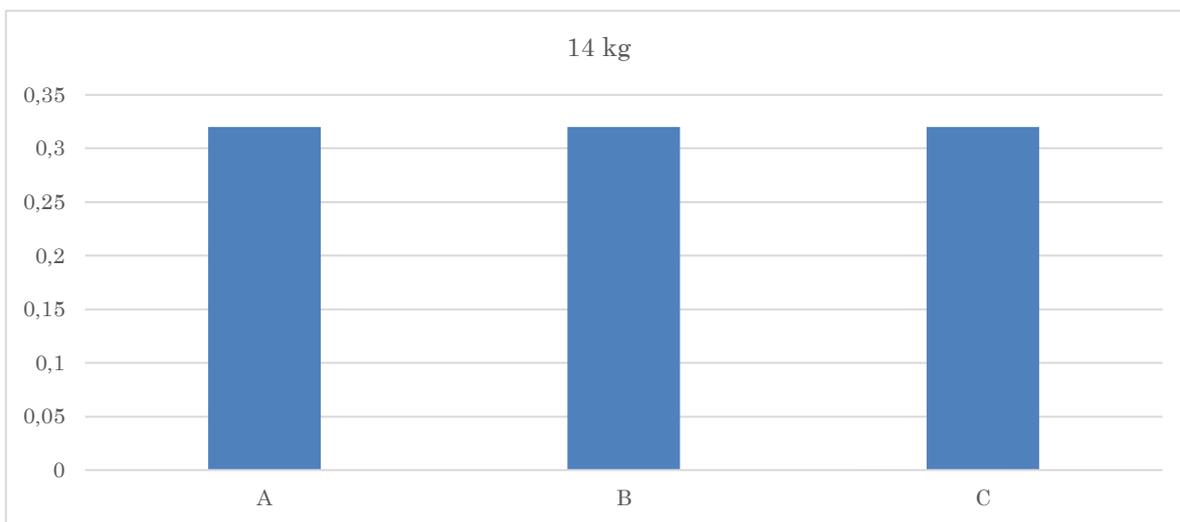


Figure 16. Effect of chimney height variation on solar dryer efficiency based on raw material mass

3.7. Organoleptic

The average values of the analysis results of products dried using dryers A, B, and C with variations in chimney height and a duration of 14 hours can be seen in Figure 6. Cascara coffee has a significant effect on the color, aroma, and taste of coffee fruit waste, as shown in Table 1.

Table 1. Average sample values from organoleptic testing

		A	B	C
7 kg	Aroma	25	21	18
	Color	25	21	18
	Taste	19	22	25
14 kg	Aroma	17	25	22
	Color	18	22	25
	Taste	16	25	21

3 CONCLUSION

Based on the research findings, several conclusions can be drawn regarding the impact of chimney height variation on the drying process of cascara coffee products. First, the drying rate is influenced by chimney height, particularly at a lighter load of 7 kg. In this case, an increase in chimney height leads to a significant decrease in the drying rate. On the other hand, at a heavier load of 14 kg, the drying rate remains relatively constant, suggesting that chimney height has less impact on drying when the load is heavier. Second, drying efficiency is observed to be higher at a 7 kg load compared to a 14 kg load. Among the different drying devices, Dryer A exhibits the highest efficiency, followed by Dryer B, while Dryer C shows the lowest efficiency. This indicates that both the load and the dryer design play a crucial role in drying efficiency. Lastly, the quality of the cascara coffee product, including aroma, color, and taste, is affected by drying time. After 7 hours of drying, Sample A has the best aroma, while Sample C provides the best taste. However, after 14 hours, the best aroma and taste shift to Sample B, while the color is still preferred in Sample C. Overall, the study concludes that the height of the chimney has a minimal effect on the drying rate, efficiency, and product quality. This is likely due to the narrow diameter of the chimney, which limits airflow. These insights suggest that modifications to the chimney design could enhance drying performance and product quality in the future.

AUTHOR’S CONTRIBUTIONS

All authors discussed the results and contributed to from the start to final manuscript.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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