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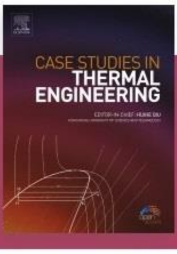

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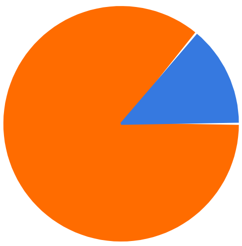

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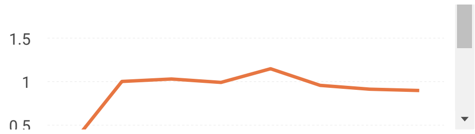

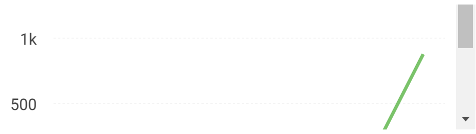

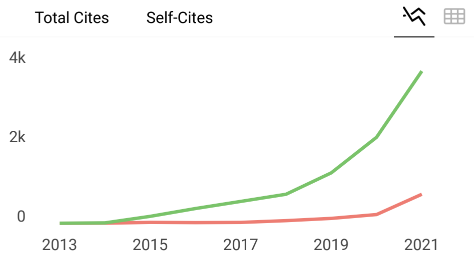

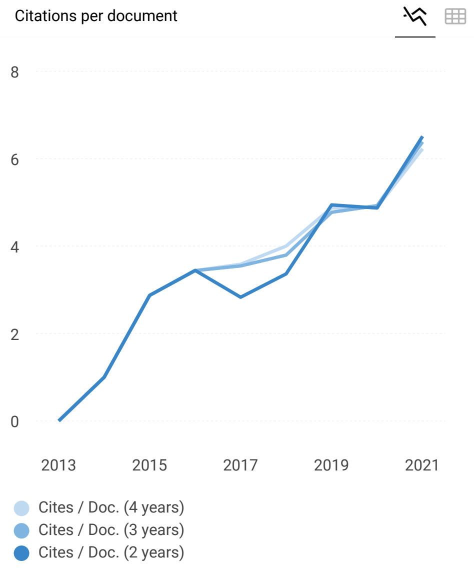

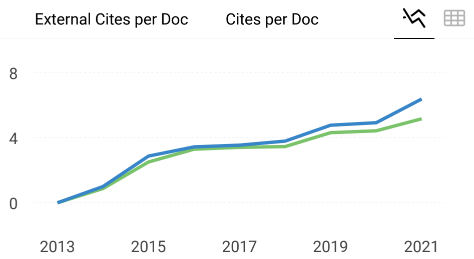

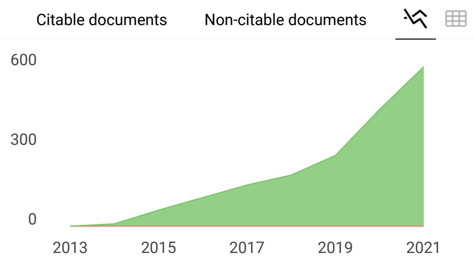

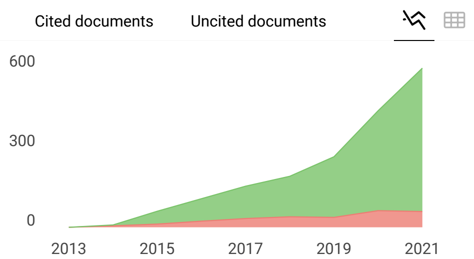

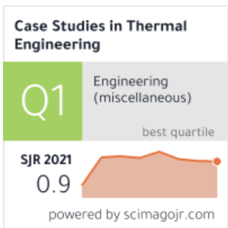

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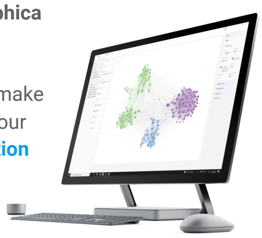

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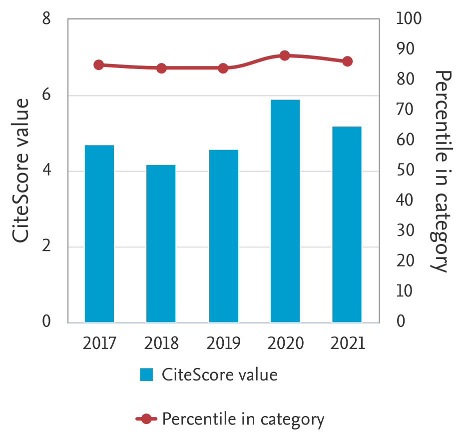

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Rice husk energy rotary dryer experiment for improved solar drying thermal performance on cherry coffee

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ABSTRACT

This research focuses on testing rotary dryers for the small-scale drying of cherry coffee, using hot air through the conversion of rice husk into thermal with a heat exchanger. Drying cherry coffee with a moisture content of 62% was dried using a rotary dryer and sun drying. Rotary dryer testing for mass variations of 10 kg, 15 kg, and 20 kg. During the drying process, rice husks are not added to the furnace. The results showed that the rotary drying temperature was higher than the sun drying. The final moisture content of sun drying was 13.14%; the average temperature was 29.44 °C for 16 days. The rotary dryer produces final moisture content of 10.71%, 10.45%, and 11.13%. The time required is 1440 min, 1680 min, and 1920 min, respectively. The fastest drying rate occurs at a mass of 10 kg. The highest drying efficiency occurs for a mass of 20 kg. The greater the mass affects the moisture content evaporation, so the drying efficiency is high. During the drying process, there is a decrease in efficiency because the energy absorbed by cherry coffee decreases as the moisture content decreases.

1. Introduction

Drying cherry coffee or coffee after being harvested is directly dried by drying in the sun requires additional work. The coffee turns process must be periodically to dry evenly and avoid mold or rot. In addition, workers are at risk of experiencing fatigue due to exposure to the sun's heat. Sun drying or natural depends on the weather, and when it is cloudy or rainy, it affects the cessation of drying activities. From the results of field observations of small farmers in the Lombok area, information is obtained that drying cherry coffee or whole with the skin gives an exotic taste or tropical fruit. Drying cherry coffee naturally takes a relatively long time due to non-optimal temperatures. Small farmers in Lombok need an effective dryer that is easy to operate at affordable and sustainable prices. The dryer model is designed with the participation of small farmers, namely using rice husk energy sources, producing evenly dry products, and optimal temperatures.

The dryer design is adapted to the needs of small farmers who do dry coffee processing. Dry coffee processing, namely the stripping of fruit flesh, skin horns, and epidermis, is done after drying. In order to avoid chemical changes and fermentation affecting the coffee's quality, drying should be done as soon as possible [1]. The sun drying process, or natural, is very weather dependent and takes about 3–4 weeks to reach a moisture content of 12%. Drying time can be accelerated using artificial dryers. Based on the participation of small farmers as users, biomass, especially rice husks, is used as an energy source. The participatory approach benefits the procurement of work tools, reduces the physical workload, and is the most effective way to redesign manual tasks [2,3]. Rice husks with abundant

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production are used only to warm livestock and cook by direct burning, and the rest is burned. The potential for rice husks in Lombok and West Nusa Tenggara based on 2020 data are 269,420.20 tons and 533,150.80 tons, respectively and have a calorific value equivalent to half the calorific value of coal of 11–15.3 MJ/kg; the maximum temperature for direct combustion and using a stove are 560 °C and 556.5 °C, respectively; contains cellulose, lignin, and silica, so it is suitable for the use of heat energy [4–8]. Utilization of rice husks for drying energy through an energy conversion process using a heat exchanger.

The heat exchanger is applied for heat transfer from burning rice husks to the ambient air. The heat transfer process is due to the difference in temperature between two fluids separated by a wall by utilizing a heat exchanger [9]. Heat exchanger with single pass tube has been applied in several drying processes with biomass energy sources. The tubes are placed in a single furnace for burning rice husks to optimize heat transfer to the ambient air [10–12]. In this study, it was found that the ambient temperature was optimal for the drying process. In addition, the tests carried out to dry small-scale food ingredients such as jackfruit *dodol* and corn can produce clean and hygienic products in a shorter time than natural drying. The heat exchanger tubes transfer hot air to the drying chamber in the form of a vertical shelf. The selection of fixed-tube heat exchangers facilitates wider utilization and traditionally minimizes total annual costs [13]. The utilization of biomass can meet the energy needs of rural communities in developing countries, improve their economic status, and reduce firewood use [14,15]. The application of biomass dryers increases the drying temperature so that it does not cause losses to the agricultural sector. Improper drying facilities cause losses to the agricultural sector because the drying operation unit is the highest and most important post-harvest energy consumption [16,17]. The energy consumption of the drying process accounts for about 60% of the energy consumption of the entire production process, as in tobacco [18]. The biomass dryer application is adapted to the food to be dried. For grains such as cherry coffee, more require a rotary dryer. It is intended that the drying temperature is uniform to produce an even dry product.

Rotary-type dryers are in the form of a cylinder or drum that rotates continuously and obtains heat from an energy source such as biomass. This model is very suitable for granular foods such as grains. Rotary drums are widely used for granular materials in heating, cooling, mixing, and drying processes [19–21]. Low costs are needed by small farmers in the post-harvest drying process. The design of the dryer is adapted to the waste energy, which is easy to obtain and inexpensive. Rotary dryer applications are an alternative because they provide uniform drying, are easy to operate, and are low-cost. Rotary dryers consume 15–30% less specific energy and have low maintenance costs [22]. Indirect biomass drying using a rotary dryer is better, with a smaller diameter, slimmer shape, and length [23].

The drying process is carried out for coffee in the form of cherries, namely coffee cherries that are harvested with moisture content ranging from 60 to 65%. This method is a dry process or does not involve water during processing. Coffee beans are still protected by the skin of the fruit flesh, mucus layer, horn skin, and epidermis in dry conditions [24]. The drying process is carried out to reduce the moisture content to a certain extent. Drying uses an indirect heating system to prevent contamination of smoke from burning fuel to the surface or into the coffee beans. The research was conducted to increase the sun drying temperature with a rotary dryer that can produce a uniform temperature. The dryer model uses rice husk as an energy source through the energy conversion method with a heat exchanger that is easy for small farmers to operate. Research also compares with direct sun drying.

2. Materials and methods

The research was conducted to test the rotary dryer on the cherry coffee drying process. The drying system is a continuation of the development of previous research conducted by Alit et al. [25,26], which is based on user participation according to the needs of small

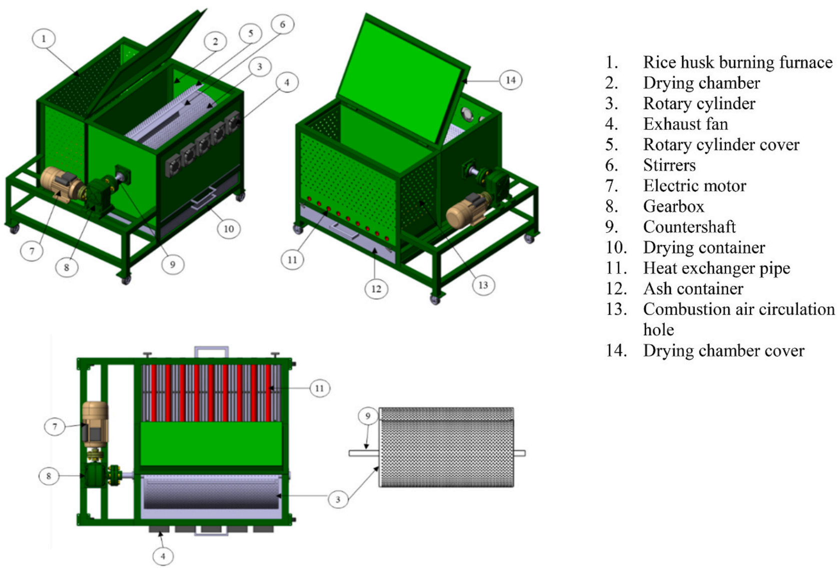

Fig. 1. Rotary dryer design with rice husk energy.

farmers. Utilization of a rotary dryer to produce a uniform temperature in the drying chamber so that food in the form of grains can dry evenly. Dryer design tailored to the needs of small farmers. Materials and tools used include cherry coffee, rice husks, iron plates, iron boxes, stainless steel plates, stainless steel pipes, iron shafts, 1 Hp dynamo, gearbox, insulating rubber, trolly wheels, transmission systems, drying cylinders, exhaust fans, type K thermocouple, rotary cylinder, and data logger.

The dryer consists of a combustion furnace, a heat exchanger, and a drying chamber. A furnace is a place for burning rice husk waste. The combustion furnace is placed next to the drying chamber. The combustion furnace is equipped with air circulation holes, ash reservoirs, and heat exchange pipes. The heat exchanger is placed inside at the bottom of the furnace. The heat exchanger connects the furnace to the drying chamber. The heat energy generated in the combustion furnace will be transferred to the drying chamber in two ways. First, conduction through the walls of the furnace with the walls of the drying chamber. Second, with forced convection due to the pull of air from the exhaust fan through the heat exchanger pipes. This study used two exhaust fans with a constant speed of 2 m/s and an area of 0.01 m^2 for each exhaust fan. This heat transfer method ensures that the product to be dried is not contaminated with combustion gases. The placement of the heat exchanger pipe at the bottom of the furnace is due to the characteristics of rice husk burning, which starts from the bottom and propagates to the surface of the husk pile.

The drying chamber consists of two cylinders. The outer cylinder is a non-circular fixed cylinder that is directly connected to the furnace. This cylinder will receive heat from the combustion of rice husks. The second cylinder is placed inside the fixed cylinder. This cylinder can rotate due to the pull of an electric motor which is transmitted by gear transmission. The drying load, namely cherry coffee, is placed in this cylinder and will rotate following the rotation of the cylinder. Several fins are installed in the rotary cylinder for faster or even load drying. The inner wall of the rotary cylinder is made not smooth, making small holes on its surface. This provides an even heat transfer effect. In addition, slightly rough circular cylinders provide better heat transfer rates than smooth tubes [27]. The test uses a dryer design, as shown in Fig. 1.

The rotary cylinder is equipped with a cover that serves as a place to enter the initial product and remove the dry product. In addition, it is also equipped with storage for dry products resulting from the drying process. The dimensions of the rotary cylinder are an inner diameter of 400 mm, a length of 800 mm, and a thickness of 20 mm. The dimensions of the furnace are 920 mm × 600 mm x 570 mm, with a capacity of 18 kg of rice husks. The length and diameter of the heat exchanger pipes are 450 mm and 1 inch, respectively. The study was conducted to evaluate the performance of a rotary dryer in drying cherry coffee and comparing it with sun drying. The rotary dryer test was carried out for the treatment of a constant amount of rice husks, namely 18 kg, and there was no addition of rice husk mass during the test. Evaluation based on drying time, drying temperature, coffee moisture content, and drying rate. The mass of cherry coffee samples for drying using a rotary dryer was varied, including 10,000 g, 15,000 g, and 20,000 g. For direct sun drying, use a sample of 2000 g. The test is carried out through a process of drying in the sun, as has been done so far by small farmers in the Lombok area. The sample test method is shown in Fig. 2.

The research data measured were ambient temperature, heat exchanger pipe temperature, drying chamber temperature, drying time, initial mass, and dry mass of cherry coffee. Based on these data, it can be calculated the heat required for drying, energy transfer from the air to the material, moisture content, drying rate, and drying efficiency. The heat used for drying Q (kJ) is in Equation (1).

$$Q = Q_1 + Q_2 + Q_3 \tag{1}$$

Q_1 is the heat for heating the material water (kJ). Q_2 is the amount of heat to evaporate the water (kJ) [28,29]. Q_3 is the sensible heat of water (kJ).

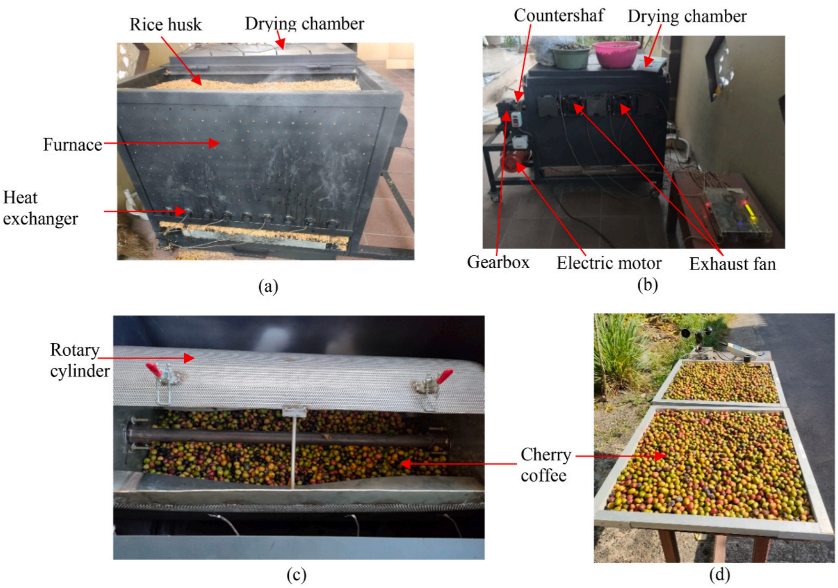

Fig. 2. Testing cherry coffee samples (a, b, c) rotary dryer with rice husk energy, (d) direct sun drying.

$$Q_1 = m_t.C_{pb}(T_b - T_a) \quad (2)$$

$$Q_2 = m_w.h_{fg} \quad (3)$$

$$Q_3 = m_a.C_{pa}(T_b - T_a) \quad (4)$$

$$m_a = m_t.K_{ai} \quad (5)$$

C_{pb} is the specific heat of cherry coffee (kJ/^{o}C). C_p coffee is taken based on Mulato [31] of 1.69 kJ/kg.^{o}C. T_b is the cherry coffee temperature (^{o}C), T_a is the ambient temperature (^{o}C), h_{fg} is the latent heat of vaporization of water (kJ/kg), m_t is the initial cherry coffee mass (kg), m_a is the mass of water, and K_{ai} is the moisture content early of the coffee early.

The heat provided by hot air to the material being dried or q (kJ) is calculated using Equation (6) [9,30].

$$q = \rho_u.V_u.C_{pu}(T_{in} - T_{out}) \quad (6)$$

ρ_u is the density of drying air (kg/m^3) and C_{pu} is the specific heat of air (kJ/kg^{o}C). T_{in} is the inlet air temperature, and T_{out} is the outlet air temperature. V_u is the volume of air entering the drying chamber (m^3); U is the velocity of the air leaving the exhaust fan (m/s); cross-section of air to the outside, namely the exhaust fan area, A (m^2); and drying time, t (s) as in Equation (7).

$$V_u = U.A.t \quad (7)$$

The coffee cherry mass consists of the initial mass, m_t (kg), and dry mass, m_k (kg). The moisture content test is carried out by heating the material until there is no change in mass so that the moisture content in the material runs out (dry mass of the material). In testing the moisture content of coffee, heating is carried out on 200 g samples for 13 h at a temperature of 105–110 °C. In this study, it was found that under these conditions, there was no change in the mass of cherry coffee. The initial and dry masses are used to calculate the moisture content, K_a (%) [32–34].

$$K_a = \frac{m_t - m_k}{m_t} \ x\ 100\% \quad (8)$$

Drying rate, $\dot{m}_p$ (kg/h) is calculated based on the ratio of the mass of water evaporated, m_w (kg), with drying time, t (h) [35,36].

$$\dot{m}_p = \frac{m_w}{t} \quad (9)$$

m_w calculated based on the mass of cherry coffee after drying, m_p (kg), and early cherry coffee mass, m_t (kg).

$$m_w = m_t - m_p \quad (10)$$

Calculation of drying efficiency using the ratio of the heat used for drying, Q (kJ), with the energy transfer from the air to the material being dried, q (kJ) [37].

$$\eta = \frac{Q}{q} \ x\ 100\% \quad (11)$$

3. Results and discussions

Based on the test results by heating for 13 h at a temperature of 105–110 °C and calculations using Equation (8), the moisture content of the early cherry coffee is 62%. The measurement results of cherry coffee showed that the initial condition of the moisture content was 62%. The drying process using a rotary dryer shows different drying times for each mass variation. Found the longest drying time in cherry coffee testing with a solar dryer. The study found that for a constant mass of rice husks, drying time with a rotary dryer occurred in 3–4 days, with one drying process taking 480 min. This occurs due to the absence of additional rice husks in the furnace. For cherry coffee samples that were dried in direct sunlight, it took 16 days to reach a moisture content of 13.14%. Meanwhile,

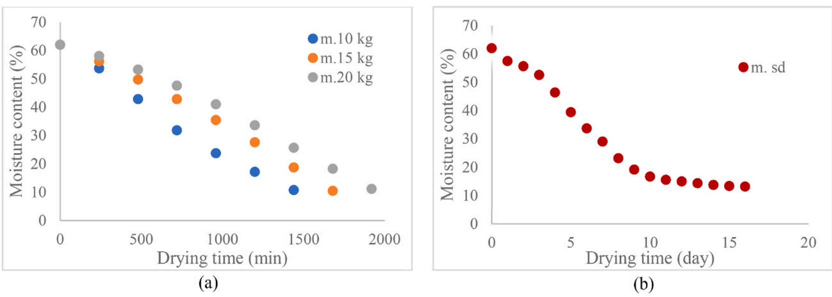

Fig. 3. Comparison of cherry coffee drying time between (a) rotary dryer and (b) direct sun.

cherry coffee, which was dried using a rotary dryer, produced a final moisture content of 10.45–11.13%. Fig. 3 shows the comparison of drying time between rotary dryers and the sun to produce the final moisture content of cherry coffee.

The drying time is much longer in sun drying because the temperature is not optimal. The rotary dryer was found to use up the mass of 18 kg of rice husks in 480 min for one drying process. This timeout is used as a reference for testing cherry coffee mass variations on a rotary dryer. There was a difference in the length of dry time on the variation of the mass, namely 10 kg (m.10 kg), 15 kg (m.15 kg), and 20 kg (m.20 kg), respectively 1440 min, 1680 min, and 1920 min. The sample is considered dry based on the quality requirements of the final moisture content. General quality requires maximum coffee moisture content of 12.5% [38]. Rotary dryers do not depend on the ambient temperature, so the drying time is much shorter than sun drying. An illustration can be seen in Fig. 4, representing the temperature distribution with a rotary dryer during the drying process. T_a is the ambient temperature, T_{out} is the exit temperature of the drying chamber, T_r is the temperature of the drying chamber, and T_{in} is the outlet temperature of the heat exchanger pipe entering the drying chamber. The existence of a heat transfer process from the combustion of husks to the ambient air flowing in the heat exchanger pipes results in a significant increase in temperature. This hot air is flowed into the rotary drying chamber to dry the cherry coffee. The temperature distribution follows the pattern of the exit temperature of the heat exchanger pipe. This temperature is the input temperature of the drying chamber. The drying chamber inlet temperature (T_{in}) for drying 10 kg, 15 kg, and 20 kg cherry coffee each reached an average of 122.54 °C (with a range of 64.95–185.03 °C), 100.90 °C (with a range of 51,48–153.09 °C), 93.38 °C (with a range of 59.94–155.95 °C). The temperature pattern follows the process of burning rice husks in the furnace.

Rice husk that is burned directly in the furnace begins with the process of evaporation of the moisture content of the rice husk. This process serves as a drying zone before further heating occurs. This is because rice husks still contain a moisture content of 8.8% [39]. The impact on the initial temperature has not increased significantly. The temperature increases when there is a process of changing rice husks into charcoal. When the rice husk is in the form of charcoal, the highest temperature is produced and reaches more than 150 °C. As the rice husks burn out and turn to ashes, it is followed by a decrease in temperature. This is a result of this research not adding rice husks to the furnace. With almost the same ambient temperature (T_a), the test on cherry coffee with a mass of 10 kg gave a higher drying temperature (T_r) than the mass of 15 kg and 20 kg. As an impact on the larger mass, this difference requires higher heat to evaporate the moisture content. The average ambient temperature (T_a) on drying with a mass of 10 kg, 15 kg, and 20 kg were 29.51 °C, 29.27 °C, and 29.53 °C, respectively. Each mass's average drying chamber temperature (T_r) is 58.05 °C, 53.07 °C, and 50.83 °C, respectively. Temperature affects the amount of heat supplied by hot air to the coffee cherry, as shown in Fig. 5. From Fig. 5 for an evaluation carried out every 5 min, the heat supplied by hot air to cherry coffee based on Equation (6) in kilojoules (kJ) shows an identical pattern to the evaluation of heat flow in kilowatts (kW). Fig. 5 shows an example of the evaluation results at any time from the test on the first day, which was carried out for 480 min. For coffee cherry masses of 10 kg, 15 kg, and 20 kg, it was found at the end of the test that the total heat supplied by hot air was 43,742.21 kJ, 34,419.19 kJ, and 30,667.61 kJ, respectively. The average heat flow is 3.038 kW, 2.39 kW, and 2.13 kW, respectively.

Compared with solar drying, which only uses ambient temperature, the drying process occurs very slowly. Research is in line with [40,41] that an increase in temperature causes a decrease in drying time. Temperature is very influential on the occurrence of a reduction in the moisture content of the material. A higher temperature gives a more significant change in the moisture content of the material, as presented in Fig. 3. This greatly affects the drying rate and drying efficiency. The higher the change in moisture content, the faster the drying rate. For a mass of 10 kg, it takes 1440 min to reach the final moisture content of 10.71%. For masses of 15 kg and 20 kg, it takes 1680 min and 1920 min to reach the final moisture content of 10.45% and 11.13%. It is very different from direct sun

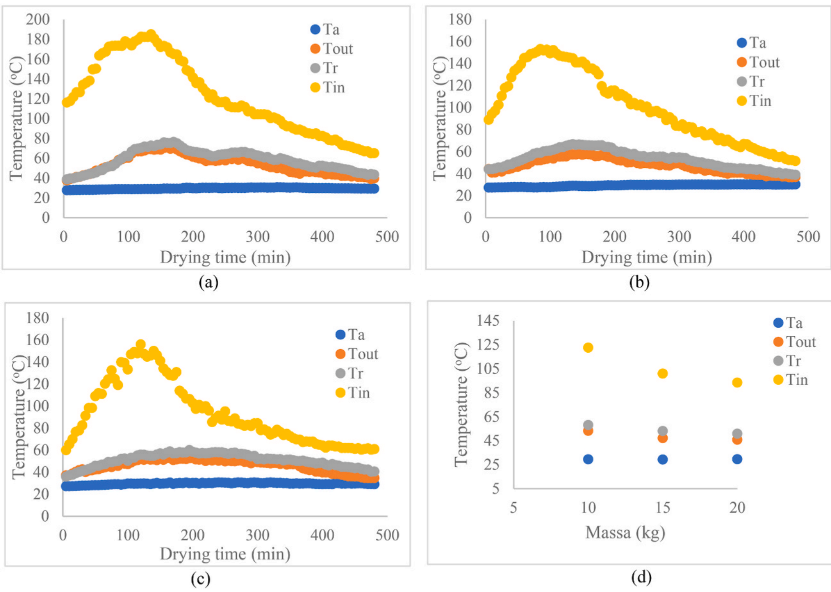

Fig. 4. Rotary dryer temperature distribution pattern on cherry coffee drying with mass (a) 10 kg, (b) 15 kg, (c) 20 kg, (d) average ratio.

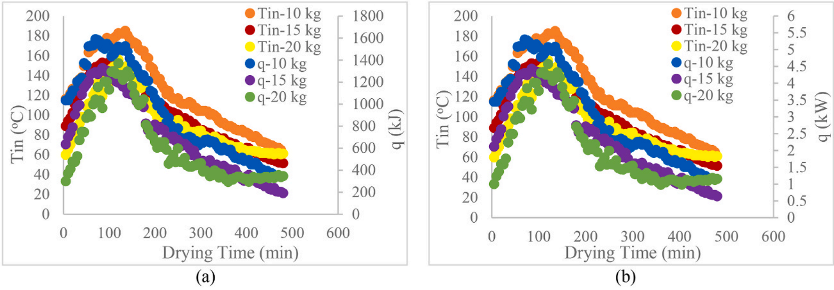

Fig. 5. Heat supplied by hot air to cherry coffee is (a) kJ and (b) kW.

drying, with a test time of 16 days, only able to produce a final moisture content of 13.14%. This is a result of the drying temperature not optimal. Drying only uses ambient temperature with an average of 29.44 °C. Lower temperatures result in longer operating times [42]. Increasing the drying temperature causes the drying rate to be faster. Comparison of drying rates using a rotary dryer on the variation of cherry coffee load per hour as presented in Fig. 6a. In this study found that the drying rate with a mass of 10 kg (m.10 kg) was faster than that of a mass of 15 kg (m.15 kg) and 20 kg (m.20 kg). It is strongly influenced by the drying temperature and mass of the material, as shown in Fig. 4. The drying rate after reaching the peak then decreases as the moisture content decreases, as shown in Fig. 6c. The increase in drying rate resulted in the loss of free moisture due to sensible heat transfer to the cherry coffee sample then the rate decreased after reached the peak drying rate. The high drying rate occurs when the moisture content of cherry coffee is still high. Found that the drying rate is directly proportional to the moisture content. The moisture content decreases, followed by the drying rate decreases. This is in line with research [43] that the drying rate is relatively higher at higher moisture content. Fig. 6b shows the drying efficiency during the cherry coffee test time and is calculated according to the moisture content measurement carried out every 240 min. The drying efficiency decreases following the decrease in the moisture content of the cherry coffee. High drying efficiency occurs because the moisture content in cherry coffee is still high. The highest drying efficiency occurs for a drying mass of 20 kg. It was found that the moisture content was much higher in the largest mass.

In this study, drying efficiency is calculated every 240 min because it follows the measurement of moisture content carried out every 240 min. In the first 240 min, the drying efficiency for each mass of 10 kg, 15 kg, and 20 kg was 15.02%, 21.73%, and 25.39%. At the end of the test, at 1440 min for a mass of 10 kg, minutes 1680 for a mass of 15 kg, and minutes 1920 for a mass of 20 kg, the efficiency reached 3.64%, 7.28%, and 9.51%, respectively. This is in accordance with [44] that high efficiency occurs in the initial drying due to the high energy of the dryer, which is absorbed by the product, and during the drying process, the energy absorbed by the product is reduced due to the reduced moisture content. Dryer efficiency decreases due to the process of reducing the moisture content of cherry coffee. This condition occurs because the heat used for drying is wasted more due to the lower moisture content in cherry coffee that has undergone evaporation. During the drying process at various loads found, a decrease in efficiency. This is in line with

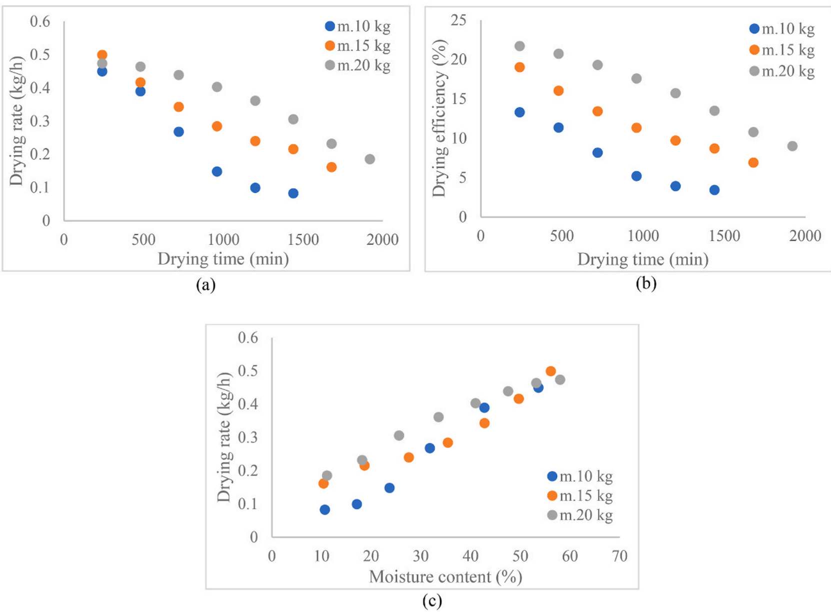

Fig. 6. Comparison of (a) drying rate with time, (b) drying efficiency, dan (c) and (c) drying rate with moisture content.

[45] that a decrease in efficiency occurs during the drying process.

4. Conclusion

Rotary type hot air dryer, through the conversion of rice husk to thermal using a heat exchanger, is applied to dry cherry coffee. Drying cherry coffee with a rotary dryer gives better results than sun drying. With the initial moisture content of cherry coffee of 62%, in the direct drying process in the sun, it takes 16 days to reach a dry moisture content of 13.14%. In comparison, the rotary dryer requires a shorter time, namely for a 10 kg cherry coffee mass which takes 1440 min and is carried out in three days to produce a dry moisture content of 10.71%. The mass of cherry coffee, 15 kg and 20 kg, lasted for four days, with a time of 1680 min and 1920 min, respectively, to achieve a dry moisture content of 10.45% and 11.13%. The drying time pattern follows the depleted rice husk mass within 480 min, with a fixed mass of 18 kg for one cherry coffee drying process. The use of a rotary dryer can increase the average environmental temperature from 29.44 °C to 58.05 °C, 53.07 °C, and 50.83 °C to dry cherry coffee with 10 kg, 15 kg, and 20 kg, respectively. The temperature impact is very significant on the drying process of cherry coffee. The higher the temperature, the faster the drying rate. Drying efficiency in the rotary dryer was found to be the highest at a mass variation of 20 kg. This is a result of the final moisture content being higher than the mass of 10 kg and 15 kg. The high moisture content affects the high energy absorption by cherry coffee from the dryer for the evaporation process. The utilization of rice husks as an energy source will add value to agricultural waste and reduce smallholder post-harvest drying costs. Rice husk is a reliable and sustainable alternative energy because it is available in abundance.

CRediT authorship contribution statement

I Gede Bawa Susana: Conceptualization, Methodology, Roles/Writing - original draft, Writing - review & editing. **Ida Bagus Alit:** Data curation, Formal analysis, Investigation, Resources. **I Dewa Ketut Okariawan:** Writing – review & editing.

Author statement

We sent an article entitled “Rice husk energy rotary dryer experiment for improved solar drying thermal performance on cherry coffee” to be published in the Journal of Case Studies in Thermal Engineering. If our article is accepted, we are ready to pay the publication fee.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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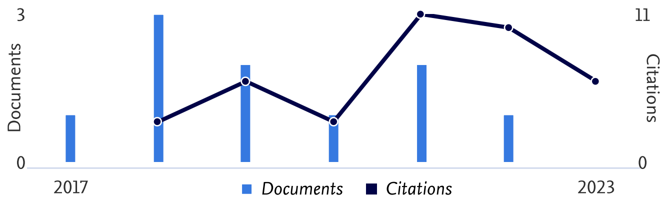

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