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THERMAL STUDY OF THE DRYER WITH HEAT EXCHANGER PIPE INSTALLED IN RICE HUSK DOUBLE FURNACE DURING DRYING WHITE TURMERIC

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ABSTRACT

The study compared solar dryers with hot air from a heat exchanger double furnace during the drying of white turmeric. Solar drying is the process of drying the product in the sun. The hot air dryer consists of two furnaces with heat exchanger pipes and a drying chamber with six vertical shelves. During the test, the use of rice husk energy in a constant amount of 35 kg. Temperature and drying rate are higher in hot air dryers. Tests carried out for 420 minutes resulted in a change in moisture content from 88% to 35.88% and an average temperature of 30.91 ºC in solar drying. For hot air, it was 2.7% at an average temperature of 73.65-119.12ºC. The distribution of the average drying temperature on shelves 1 (bottom shelf), 2, 3, 4, 5, and 6 (top shelf) are 119.12ºC, 104.99ºC, 93.24ºC, 79.99ºC, 74.69ºC, and 73.65ºC. Dryer efficiency reached 32.81% at the beginning and 4.06% at the end. At the initial drying, efficiency occurs very high because the energy absorbed by the white turmeric from the dryer is very high. During the drying process, there is a decrease in efficiency because the energy absorbed by white turmeric decreases due to reduced moisture content.

Keywords: *heat exchangers, rice husk, white turmeric*

1. INTRODUCTION

Drying is one of the post-harvest handling methods to extend the storage life of the produce. The drying process with a dryer is needed to replace the disadvantages of the sun drying process. Small farmers desperately need a dryer that is easy to operate, affordable, energy-efficient sustainable drying. As in Indonesia, especially Lombok, with unpredictable weather, small farmers need the right dryer model. The dryer model utilizes rice husk as the primary energy through a conversion process into thermal. This process will increase the temperature and speed up the drying time of post-harvest agricultural products.

One of the agricultural products of concern today is turmeric. Turmeric is a spice plant as a cooking spice, a raw material for natural medicine and traditional herbal medicine. Turmeric or white turmeric is one of the herbal products that can be used to improve the body's immune system. White turmeric is known by the scientific name Curcuma Zedoaria. White turmeric is a traditional medicinal herb that is part of history in Ayurveda (Lobo *et al*., 2009). In Indonesia, white turmeric is used as an ingredient in traditional herbal medicine and is widely consumed by many people. In the Yogyakarta Agriculture and Food Service (2021), it is explained that white turmeric functions to stimulate the immune system. This is caused by the content of specific active substances such as curcuminoide and ukanon types A, B, C, and D. To maintain the quality of turmeric, post-harvest handling is necessary, one of which is the drying process. This is because turmeric has a high moisture content at harvest of 90%. In the turmeric trade, the main product is in the form of dried turmeric. Some of the processed turmeric products include dried turmeric slices, flour, essential oils, oleoresins, and curcuminoid dyes (Manoi, 2013). To produce dry products of good quality, a dryer is needed. Inappropriate drying facilities in some developing countries cause post-harvest losses in the agricultural sector (Nguimdo and Noumegnie, 2020). A dryer will shorten the drying time, and the resulting product will be cleaner and more hygienic than drying in the sun. Drying in the sun causes the resulting product to be dusty and hard, damaging the sensory and nutritional properties, especially in vegetables and fruits (Manaa *et al*., 2013; Ochoa-Martinez *et al*., 2012). In drying turmeric by drying, it takes up to 15 days, and the impact is that some of the turmerics are exposed to fungi (Widodo and Setyawan, 2018). The use of dryers that are easy to operate, affordable, and sustainable is very much needed by small farmers. This is suitable for small-scale drying conditions, and costs are limited. The dryer model is by utilizing agricultural waste as an energy source. One of the agricultural wastes that are easily found and cheap is rice husk.

Rice husk is a by-product of rice processing. Rice production in Indonesia in 2019 was 54.6 million metric tons, and 20% was in rice husks (Shahbandeh, 2021; Hossain *et al*., 2018). For Lombok Island, rice production based on data in 2020 is 1.31 million tons of GKG (*Badan Pusat Statistik*, 2020), and the potential for rice husks is 269,420.20 tons in Lombok Island and 533,150.80 tons in West Nusa Tenggara (*RUED*, 2019). The potential of rice husk as an energy source can also be seen from its calorific value. The calorific value of rice husk is equivalent to half the calorific value of coal, namely 13-19 MJ/kg with an average of 18 MJ/kg (Smith, 2007) and 11-15.3 MJ/kg (Awulu *et al*., 2018). The maximum temperature of direct combustion in the middle of a pile of rice husks is 560ºC (Yan *et al*., 2022) and 556.5ºC in the combustion process using a stove (Tangka *et al*., 2018). Using rice husks as an energy source can reduce agricultural waste and increase the income of small farmers. Biomass energy sources can expand economic status and meet the energy needs of rural communities in developing countries (Ul Haq *et al*., 2020). Rice husk is used as an energy source and produces clean and hygienic drying products through an energy conversion process. The energy conversion method uses a heat exchanger added to the furnace. Heat exchanger functions in the heat transfer process of two fluids with

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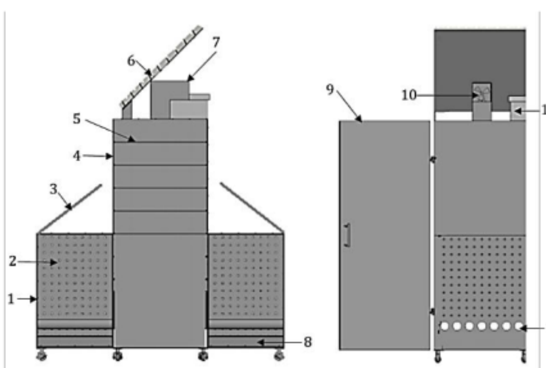
different temperatures and are separated by walls (Incropera *et al.*, 2006). This method produces hot air, which is used for the drying process. This method has been used in several studies on various types of biomass and foodstuffs (Nain *et al.*, 2021; Nwokolo *et al.*, 2020; Hamdani *et al.*, 2018). The method is also used for single-pipe and furnace variations with rice husk energy (Susana *et al.*, 2019a; Susana *et al.*, 2019b; Alit *et al.*, 2020).

The community commonly uses the direct sun-drying process. Nevertheless, it depends on the weather and the relatively long drying time. NTB, including Lombok Island, produced turmeric plant production in 2020, reaching 610,626 kg (*NTB SATU DATA*, 2020). Turmeric is indispensable to the community and requires optimal drying and heating. Slow drying rate and improper heating cause a loss of nutritional and medicinal value (Lakshmi *et al.*, 2019). The high moisture content of turmeric at harvest should be reduced to a safe storage limit of 6% (Singh *et al.*, 2010). This study aims to evaluate the performance of a dryer with rice husk as the main energy to dry white turmeric on a small scale as a substitute for sun drying. The conversion of rice husk to thermal using a double furnace and heat exchanger to optimize the drying temperature. This study also compared direct sun drying.

2. MATERIALS AND METHODS

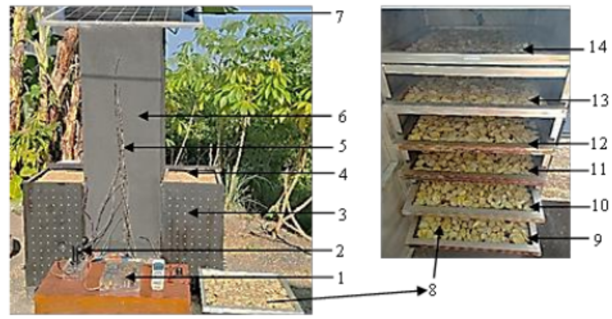
This research is the development of research Alit and Susana (2021), which utilizes rice husk as an energy source by burning in a single furnace equipped with a heat exchanger. Research development Alit and Susana (2021) through double furnace and modification of drying chamber. The study used the same dryer design by Alit *et al.* (2021) and applied it to the white turmeric drying process on the scale of small farmers. Furnace and drying chamber designs are tailored to the needs of smallholders. The materials and tools used include white turmeric, rice husks, aluminum plates, stainless steel pipes, iron plates, exhaust fans, solar panels, batteries, type K thermocouples, and data loggers. Rice husk is used as the main energy source. Post-harvest agricultural products use white turmeric. The diameter of the heat exchanger pipe is 1 inch. The furnace dimensions are 40 cm x 50 cm x 60 cm from the iron plate. The dimensions of the drying chamber are 50 cm x 50 cm x 140 cm from the aluminum plate. Solar panels and batteries as energy storage for driving the exhaust fan.



1. Furnace; 2. Air circulation holes; 3. Furnace cover; 4. Drying chamber; 5. Insulated drying shelves; 6. Solar panels; 7. Chimney; 8. Ash hole; 9. Drying chamber door; 10. Exhaust fan; 11. Accu; 12. Heat exchanger pipe

Fig. 1 Design of double furnace type dryer with rice husk energy

The dryer arrangement consists of two furnaces for directly burning rice husks and a drying chamber with six vertical shelves. At the bottom of the furnace, heat exchanger pipes are placed. Furnaces are placed on both sides of the drying chamber. Hot air in the drying chamber is obtained due to convection heat transfer from the heat exchanger pipe and conduction from the furnace. The drying chamber is isolated with 3 mm rubber insulating material and is equipped with an exhaust fan on the exhaust duct. The process of burning rice husks is assisted by the presence of air circulation holes on the walls of the furnace. The diameter of the furnace wall hole is 8 mm. This diameter is used because the resulting temperature pattern is more stable and the smallest, based on previous studies (Alit *et al.*, 2021). The study evaluated the dryer's performance in drying white turmeric and compared it with sun drying. Evaluation based on drying temperature, moisture content of white turmeric, and drying rate. The drying time was set at 420 minutes, with the measurement of the moisture content carried out every 60 minutes. The mass of the sample is 4500 grams, distributed evenly on each shelf in the drying chamber. The sample mass of each shelf is 750 grams. For direct sun drying, use a sample of 1175 grams. Before drying, white turmeric is washed and sliced lengthwise with a thickness of 3 mm. The test uses a dryer design, as shown in Fig. 1, with the sample test method shown in Fig. 2.



1. Data logger; 2. Cup anemometer; 3. Furnace; 4. Rice husk; 5. Thermocouple K type; 6. Drying chamber; 7. Solar panel; 8. White turmeric; 9. Shelf 1; 10. Shelf 2; 11. Shelf 3; 12. Shelf 4; 13. Shelf 5; 14. Shelf 6

Fig. 2 White turmeric sample testing

The research data measured were the ambient temperature, the temperature of the heat exchanger pipe, the temperature of each shelf exiting the drying chamber, the initial mass, and the dry mass of white turmeric. The moisture content, drying rate, and drying efficiency can be calculated based on these data. The mass of white turmeric includes the initial mass, mt (kg), and dry mass, m_k (kg). The dry mass of white turmeric, m_k (kg), was obtained by heating for 3 hours at a temperature of 105-110ºC. The initial and dry masses were used to calculate the moisture content, Ka (%) (Henderson and Perry, 1976; Fridh *et al.*, 2014; Hamdani *et al.*, 2018).

$$K_a = \frac{m_t - m_k}{m_t}\ 100\% \tag{1}$$

The drying rate, $\dot{m}_p$ (kg/s) was calculated based on the ratio of the mass of evaporated water, m_w (kg), to the drying time, t (hours) (Brooker *et al.*, 1992; Nazghelichi *et al.*, 2010).

$$\dot{m}_p = \frac{m_w}{t} \tag{2}$$

m_w was calculated based on the mass of white turmeric after drying m_p (kg) and the initial mass of white turmeric, m_t (kg).

$$m_w = m_t - m_p \tag{3}$$

The calculation of drying efficiency uses the ratio of the heat used for drying, Q (kJ), to the energy transfer from the air to the material being dried, q (kJ) (Çengel and Turner, 2004).

$$\eta = \frac{Q}{q}\ 100\% \tag{4}$$

Q (kJ) is the heat used for drying, as in Eq. (5).

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$$Q = Q_1 + Q_2 \tag{5}$$

Q_1 is the heat to heat the material water (kJ). Q_2 is the amount of heat evaporating the water (kJ) (Hamdani *et al*., 2018; Çengel and Boles, 2006). C_{pb} is the specific heat of white turmeric (kJ/°C), T_b is the temperature of white turmeric (°C), T_a is the ambient temperature (°C), and h_{fg} is the latent heat of evaporation of water (kJ/kg).

$$Q_1 = m_t\, C_{pb}(T_b - T_a) \tag{6}$$

$$Q_2 = m_w\, h_{fg} \tag{7}$$

Based on Eq. (4), the energy transfer from the air to the dried material or q (kJ) is calculated using Eq. (8) (Incropera *et al*., 2006).

$$q = \rho_u\, V_u\, C_{pu}(T_{in} - T_{out}) \tag{8}$$

ρ_u is the density of drying air (kg/m^3), C_{pu} is the specific heat of the air (kJ/kg.°C). T_{in} is the inlet air temperature, and T_{out} is the outlet air temperature.

3. RESULTS AND DISCUSSION

Initial measurement results show that white turmeric has a moisture content of 88%. Fig. 3 compares the moisture content of the drying process using a dryer and the sun.

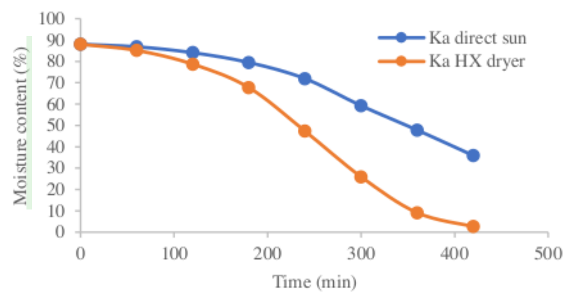

Fig. 3 The comparison of white turmeric moisture content (Ka) between direct sun drying and heat exchanger drying

The decrease in the moisture content of the material in the use of hot air is faster than direct sun drying. Hot air is generated using a double furnace dryer and heat exchanger with rice husk energy. At minute 420, white turmeric's moisture content reached 35.88% in direct sun drying, while for hot air, it reached 2.7% for all samples. The moisture content in hot air is calculated based on the total initial mass of white turmeric, 4500 grams, and a total dry mass of 540 grams. White turmeric experienced a significant decrease in moisture content when using hot air for drying. There was a decrease in the mass of the material by 88%. The moisture content of white turmeric based on all samples was calculated every 60 minutes. At 60 minutes, it is 85.108%, 120 minutes is 78.681%, 180 minutes is 67.703%, 240 minutes is 47.317%, 300 minutes is 25.926%, 360 minutes is 9.09%, and 420 minutes is 2.7%. This result is in line with Sharma *et al.* (2021), which showed that hot air drying of turmeric sliced with a thickness of 3 mm required a shorter time than direct sun drying.

Fig. 4 shows the distribution of moisture content and mass of white turmeric on each shelf in the drying chamber from drying with hot air. Slower drying occurs from 0 to 120 minutes. This follows the nature of rice husks. Namely, the combustion process begins with the evaporation of the moisture content of rice husks. Rice husk contains 8.8% moisture (Mhilu, 2014). The drying temperature increases as the rice husk turn into charcoal. The highest change in moisture content occurred in shelf 1 (ka-s1) followed by a rapid decrease in the mass of the material (ms1). The distribution of samples on each shelf is an initial mass of 750 grams with an initial moisture content of 88%. On-shelf 1, it was found that at 240 minutes, the moisture content of the material was zero, and the mass did not change, which was constant at 90 grams (ms1) until 420 minutes. On-shelf 1, it was also found that a large change in moisture content occurred from 120 to 180 minutes, from 37.9 % to 1.1%. A different phenomenon was found on the shelf above it. The moisture content of the ingredients on shelf 2 (ka-s2) at minute 360 is zero with a mass of 90 grams (ms2) and at minute 300 is 5.3% with a mass of 95 grams. On-shelf 3, the moisture content of the material (ka-s3) reaches zero at 420 minutes with a mass of 90 grams. Unlike what happened on shelves 4, 5, and 6, it was found that the moisture content of the material at the end of the test (420 minutes) was 3.2% (ka-s4), 4.3% (ka-s5), and 8.2%, respectively (ka-s6) with a final mass of 93 grams (ms4), 94 grams (ms5), and 98 grams (ms6), respectively. The drying time is shorter when compared to the study by Borah *et al.* (2015) drying slices of turmeric samples using a solar conduction dryer which takes 12 hours to effectively reduce the moisture content from 78.65% to 5.5%.

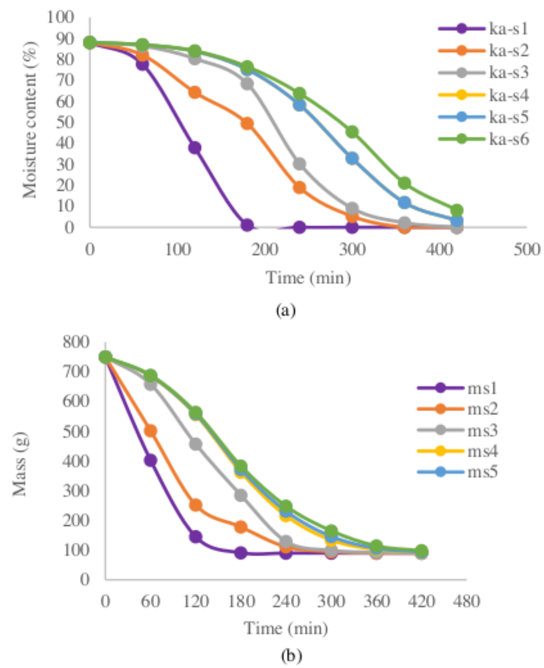

Fig. 4 The comparison of the (a) moisture content (ka-s), (b) mass (ms) of white turmeric on each shelf in the drying chamber

Differences in moisture content changes and material mass on each shelf follow the distribution pattern of hot air drying. The higher the drying temperature, the greater the reduction in moisture content of white turmeric, as shown in Fig. 5a. Shelf 1 has the closest position to the hot air source compared to shelf six, which is far away from the hot air source. This gives the impact of differences in changes in moisture content and mass of material. Based on the pattern of changes in moisture content, such as Fig. 4a, it was found that reaching the standard limit for the moisture content of dry white turmeric took a different time on each shelf in the drying chamber. This condition can be used as a reference for the drying time for each shelf. As in shelf 1, closest to the heat source, the highest drying temperature occurs, as shown in Fig. 5b. The average drying temperature on shelf 1 (Ts1) is 119.12°C with a range of 84.70-142.78°C. The highest temperature on shelf 1 compared to shelves 2, 3, 4, 5, and 6 with an average of 104.99°C (55.9-124.76°C), 93.24°C (48.02-120.79°C), 79.99°C (37.47-112.79°C), 74.69°C (41.43-95.44°C), and 73.65°C (36.15-103.22°C) respectively. The higher the drying temperature, the faster the white turmeric will decrease in moisture content. This impacts the drying process of white turmeric on shelf one, which takes more time than the shelf above. This research is in line with Waheed and Komolafe (2019); Dasore *et al*. (2020) that an increase in temperature causes a decrease in drying time. In contrast, what happened to direct sun drying with a test time of 420 minutes was only able to reduce the moisture content of white turmeric by 47.826%. This is a result of the drying temperature not optimal. Drying only uses ambient temperature with an average of 30.91ºC (29.48-32.06ºC). The lower the temperature, the longer the operating time (Bevington and Robinson, 2003). The increase in the drying temperature causes the drying rate to be faster.

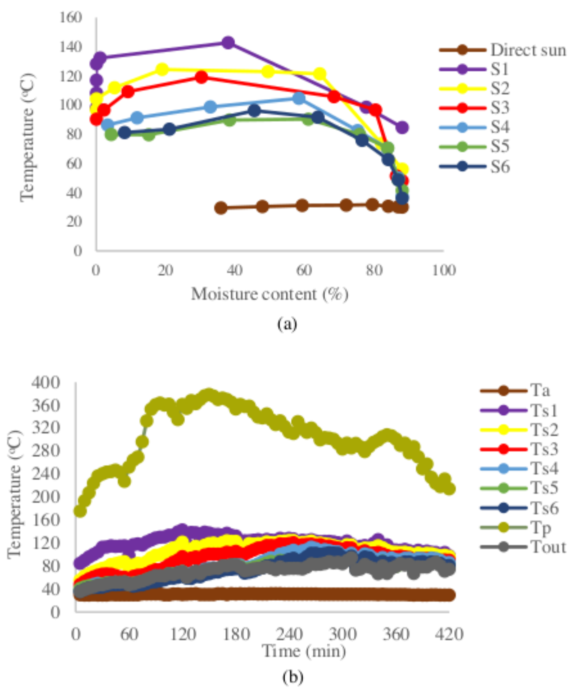

Fig. 5 (a) The comparison of white turmeric moisture content and (b) drying temperature distribution pattern

The comparison of drying rates using sun and hot air per hour is presented in Fig. 6a. In this study, it was found for a test time of 420 minutes that the drying rate using the sun (mp-direct sun) was much slower with a high-moisture content compared to using hot air. It is strongly influenced by the drying temperature as shown in Fig. 6b. Higher temperatures affect faster drying rates. The drying rate on shelf 1 (mp1) is the fastest because the drying temperature is the highest (S1). The farther the drying shelf is from the heat source, the slower the drying rate. In the use of hot air, the slowest drying rate occurs on shelf 6 (mp6). The drying rate after reaching the peak then decreases as the moisture content decreases. On-shelf 1, the drying rate (mp1) peaked at 180 minutes. On shelves 2 and 3 (mp2 and mp3) at 240 minutes, and shelves 4, 5, and 6 (mp4, mp5, mp6) at 300 minutes. Free moisture due to sensible heat transfer to the turmeric sample decreased after the peak drying rate was reached (Sharma *et al*., 2021). The high drying rate occurs when the moisture content of white turmeric is still high, as in Fig. 6c. It was found that the drying rate is directly proportional to the moisture content. As the moisture content decreases, the drying rate also decreases. For the test time of 420 minutes, the initial moisture content of the turmeric sample as a whole was 88%, decreased to 2.7% in direct proportion to the drying rate, namely the average of 145.67 g/h decreased to 6.5 g/h. This is in line with the research of Lakshmi *et al*. (2019) that the drying rate is relatively higher at higher moisture content.

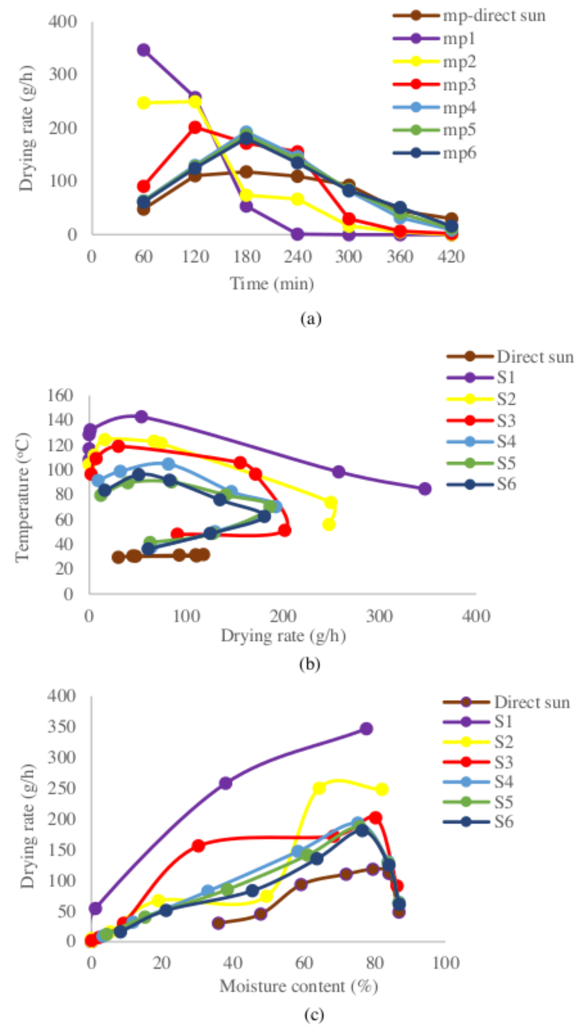

Fig. 6 The comparison of drying rate with (a) time, (b) temperature, and (c) moisture content

The slow drying rate of white turmeric with still high-moisture content occurs in direct sun drying. At the end of the test (420 minutes), the drying rate was 30 g/h. The moisture content was 35.88% with an average drying temperature of 30.91ºC. In drying white turmeric with hot air for shelf 1, it was found that the drying process was sufficient for a maximum of 180 minutes. At that time, the drying rate reached 54 g/h, moisture content 1.1%, and mass 91 g, with an average drying temperature of 119.12ºC. On-shelf 2, the drying process can be carried out for 300 minutes. In this condition, the drying rate reached 16 g/h, moisture content 5.3%, and mass 95 g, with an average drying temperature of 104.99ºC. On-shelf 3, the drying process can be carried out for 300-360 minutes. In this condition, the drying rate reaches 30-7 g/h, moisture content 9.1-2.2%, mass 99-92 g, with an average drying temperature of 93.24ºC. On shelves 4 and 5, the drying process can be carried out for 360-420 minutes. In this condition, each drying rate reached 32-9 g/h and 40-12 g/h, moisture content 11.8-3.2% and 15.1-4.3%, mass 102-93 g and 106-94 g, with an average drying temperature of 79.99ºC and 74.69ºC. On-shelf 6, the drying process can be carried out for 420 minutes. In this condition, the drying rate reached 16 g/h, moisture content 8.2%, and mass 98 g, with an average drying temperature of 73.65ºC. The results of the dry moisture content test follow the required standards. During the test, there was no additional mass of fuel, so the drying temperature changed after burning rice husks that burned out longer. The moisture content of dried turmeric has different standards or requirements. Singh *et al.* (2010) state that the safe limit for storage is 6%. The dry moisture content for turmeric slices with a thickness of 3 mm dried using a dryer is 6.9%, and the maximum US trade quality standard is 9% (Manoi, 2013). The study by Sharma *et al.* (2021) showed the moisture content of sliced turmeric with a thickness of 3 mm, which was dried using hot air within 2.5 hours, was 3.33%. Changes in moisture content were followed by changes in dryer efficiency, as presented in Fig. 7.

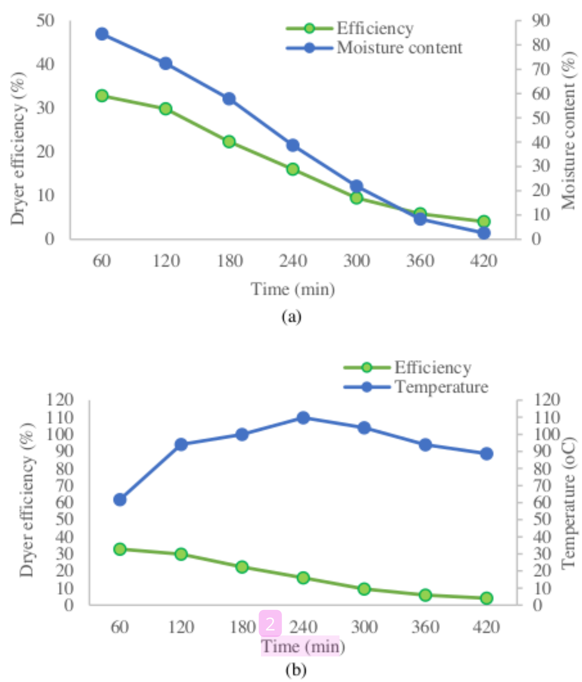

Fig. 7 Distribution pattern of dryer efficiency, moisture content, and temperature against time

Fig. 7 shows the dryer's efficiency during the testing time of the white turmeric sample and is calculated according to the moisture content measurement carried out every 60 minutes. Fig. 7 also shows the effect of temperature on dryer efficiency. The efficiency of the dryer decreases following the decrease in the moisture content of white turmeric. Dryer efficiency can reach 32.81% at minute 60. This is due to the moisture content in white turmeric being still high. At the end of the test, at minute 420, the efficiency reached 4.06%. This follows Djaeni *et al.* (2019), very 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. In the study, it was found that for 240 minutes, an increase in drying temperature was seen, followed by a decrease in drying efficiency. For 240 minutes, there was a decrease in the high moisture content of white turmeric by 43.98%, from an average of 88% to 38.71%. Drying efficiency decreased due to reducing the high moisture content in white turmeric. Different that happened from 240 minutes to 420 minutes. A decrease follows the drying temperature decrease in the dryer's efficiency. This condition occurs because the heat used for drying is more wasted due to the smaller moisture content in white turmeric that has undergone evaporation.

The decrease in moisture content of white turmeric from 240 to 420 minutes was relatively small at 6.74%, namely from an average of 38.71% to 2.61%. Efficiency decreases during the drying process (Balbine *et al.*, 2015). The decrease in drying temperature occurred because, during the drying process, the amount of rice husk was constant in both furnaces, each 17.5 kg or 35 kg. Testing on white turmeric using a desiccant design from the research of Alit *et al.* (2021) showed that the dryer's performance showed good results. This can be seen from the short drying time for white turmeric samples on the scale of small farmers, which is 4500 grams.

4. CONCLUSIONS

A double furnace-type hot air dryer and heat exchanger with rice husk energy were applied to dry white turmeric. White turmeric dried using hot air gives better results than sun drying. The drying process was carried out with white turmeric sliced 3 mm thick with an initial moisture content of 88% with a drying time of 420 minutes.

- Drying with hot air can achieve an overall final moisture content of 2.7%. While the final moisture content using sun drying is 35.88%.
- The sun-drying temperature, with an average of 30.91°C, is much lower than the hot air dryer, which reaches an average of 90.95°C.
- On each shelf in the drying room, there is a difference in drying time to reach the final moisture content of white turmeric. The moisture content on shelf one within 180 minutes reached 1.1% with an average drying temperature of 119.12°C. The longest occurs on shelf 6, which is within 420 minutes. The moisture content reaches 8.2% with an average drying temperature of 73.65°C.
- The highest drying efficiency occurred at the beginning of the drying process, namely 32.81%, and the lowest occurred at the end, 4.06%. This occurs due to the influence of the high initial moisture content. During drying, the moisture content of the material evaporates, which impacts the energy absorption process by white turmeric from the dryer.
- Using 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.
- Further research is needed to reduce the relatively high fluctuation of drying temperature by adding a thermostat and exhaust fan.

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Frontiers in Heat and Mass Transfer Available at www.ThermalFluidsCentral.org THERMAL STUDY OF THE DRYER WITH HEAT EXCHANGER PIPE INSTALLED IN RICE HUSK DOUBLE FURNACE DURING DRYING WHITE TURMERIC Ida Bagus Alit, I Gede Bawa Susana*, I Made Mara Department of Mechanical Engineering, Faculty of Engineering, University of Mataram, Jl. Majapahit No. 62 Mataram-Nusa Tenggara Barat 83125 Indonesia ABSTRACT The study compared solar dryers with hot air from a heat exchanger double furnace during the drying of white turmeric. Solar drying is the process of drying the product in the sun. The hot air dryer consists of two furnaces with heat exchanger pipes and a drying chamber with six vertical shelves. During the test, the use of rice husk energy in a constant amount of 35 kg. Temperature and drying rate are higher in hot air dryers. Tests carried out for 420 minutes resulted in a change in moisture content from 88% to 35.88% and an average temperature of 30.91oC in solar drying. For hot air, it was 2.7% at an average temperature of 73.65-119.12oC. The distribution of the average drying temperature on shelves 1 (bottom shelf), 2, 3, 4, 5, and 6 (top shelf) are

119.12oC, 104.99oC, 93.24oC, 79.99oC, 74.69oC, and 73.65oC. Dryer efficiency reached 32.81% at the beginning and 4.06% at the end. At the initial drying, efficiency occurs very high because the energy absorbed by the white turmeric from the dryer is very high. During the drying process, there is a decrease in efficiency because the energy absorbed by white turmeric decreases due to reduced moisture content. Keywords: heat exchangers, rice husk, white turmeric 1. INTRODUCTION Drying is one of the post-harvest handling methods to extend the storage life of the produce. The drying process with a dryer is needed to replace the disadvantages of the sun drying process. Small farmers desperately need a dryer that is easy to operate, affordable, energy-efficient sustainable drying. As in Indonesia, especially Lombok, with unpredictable weather, small farmers need the right dryer model. The dryer model utilizes rice husk as the primary energy through a conversion process into thermal. This process will increase the temperature and speed up the drying time of post-harvest agricultural products. One of the agricultural products of concern today is turmeric. Turmeric is a spice plant as a cooking spice, a raw material for natural medicine and traditional herbal medicine. Turmeric or white turmeric is one of the herbal products that can be used to improve the body's immune system. White turmeric is known by the scientific name Curcuma Zedoaria. White turmeric is a traditional medicinal herb that is part of history in Ayurveda (Lobo et al., 2009). In Indonesia, white turmeric is used as an ingredient in traditional herbal medicine and is widely consumed by many people. In the Yogyakarta Agriculture and Food Service (2021), it is explained that white turmeric functions to stimulate the immune system. This is caused by the content of specific active substances such as curcuminoide and ukanon types A, B, C, and D. To maintain the quality of turmeric, post-harvest handling is necessary, one of which is the drying process. This is because turmeric has a high moisture content at harvest of 90%. In the turmeric trade, the main product is in the form of dried turmeric. Some of the processed turmeric products include dried turmeric slices, flour, essential oils, oleoresins, and curcuminoid dyes (Manoi, 2013). To produce dry products of good quality, a dryer is needed. Inappropriate drying facilities in some developing countries cause post-harvest losses in the agricultural sector * Corresponding author. Email: gedebawa@unram.ac.id (Nguimdo and Noumegnie, 2020). A dryer will shorten the drying time, and the resulting product will be cleaner and more hygienic than drying in the sun. Drying in the sun causes the resulting product to be dusty and hard, damaging the sensory and nutritional properties, especially in vegetables and fruits (Manaa et al., 2013; Ochoa-Martinez et al., 2012). In drying turmeric by drying, it takes up to 15 days, and the impact is that some of the turmerics are exposed to fungi (Widodo and Setyawan, 2018). The use of dryers that are easy to operate, affordable, and sustainable is very much needed by small farmers. This is suitable for small-scale drying conditions, and costs are limited. The dryer model is by utilizing agricultural waste as an energy source. One of the agricultural wastes that are easily found and cheap is rice husk. Rice husk is a by-product of rice processing. Rice production in Indonesia in 2019 was 54.6 million metric tons, and 20% was in rice husks (Shahbandeh, 2021; Hossain et al., 2018). For Lombok Island, rice production based on data in 2020 is 1.31 million tons of GKG (Badan Pusat Statistik, 2020), and the potential for rice husks is 269,420.20 tons in Lombok Island and 533,150.80 tons in West Nusa Tenggara (RUED, 2019). The potential of rice husk as an energy source can also be seen from its calorific value. The calorific value of rice husk is equivalent to half the calorific value of coal, namely 13-19 MJ/kg with an average of 18 MJ/kg (Smith, 2007) and 11-15.3 MJ/kg (Awulu et al., 2018). The maximum temperature of direct combustion in the middle of a pile of rice husks is 560oC (Yan et al., 2022) and 556.5oC in the combustion process using a stove (Tangka et al., 2018). Using rice husks as an energy source can reduce agricultural waste and increase the income of small farmers. Biomass energy sources can expand economic status and meet the energy needs of rural communities in developing countries (Ul Haq et al., 2020). Rice husk is used as an energy source and produces clean and hygienic drying products through an energy conversion process. The energy conversion method uses a heat exchanger added to the furnace. Heat exchanger functions in the heat transfer process of two fluids with different temperatures and are separated by walls (Incropera et al., 2006). This method produces hot air, which is used for the drying process. This method has been used in several studies on various types of biomass and foodstuffs (Nain et al., 2021; Nwokolo et al., 2020; Hamdani et al., 2018). The method is also used for single-pipe and furnace variations with rice husk energy (Susana et al., 2019a; Susana et al., 2019b; Alit et al., 2020). The community commonly uses the direct sun-drying process. Nevertheless, it depends on the weather and the relatively long drying time. NTB, including Lombok Island, produced turmeric plant production in 2020, reaching 610,626 kg (NTB SATU DATA, 2020). Turmeric is indispensable to the community and requires optimal drying and heating. Slow drying rate and improper heating cause a loss of nutritional and medicinal value (Lakshmi et al., 2019). The high moisture content of turmeric at harvest should be reduced to a safe storage limit of 6% (Singh et al., 2010). This study aims to evaluate the performance of a dryer with rice husk as the main energy to dry white turmeric on a small scale as a substitute for sun drying. The conversion of rice husk to thermal using a double furnace and heat exchanger to optimize the drying temperature. This study also compared direct sun drying. 2. MATERIALS AND METHODS This research is the development of research Alit and Susana (2021), which utilizes rice husk as an energy source by burning in a single furnace equipped with a heat exchanger. Research development Alit and Susana (2021) through double furnace and modification of drying chamber. The study used the same dryer design by Alit et al. (2021) and applied it to the white turmeric drying process on the scale of small farmers. Furnace and drying chamber designs are tailored to the needs of smallholders. The materials and tools used include white turmeric, rice husks, aluminum plates, stainless steel pipes, iron plates, exhaust fans, solar panels, batteries, type K thermocouples, and data loggers. Rice husk is used as the main energy source. Post-harvest agricultural products use white turmeric. The diameter of the heat exchanger pipe is 1 inch. The furnace dimensions are 40 cm x 50 cm x 60 cm from the iron plate. The dimensions of the drying chamber are 50 cm x 50 cm x 140 cm from the aluminum plate. Solar panels and batteries as energy storage for driving the exhaust fan. 1. Furnace; 2. Air circulation holes; 3. Furnace cover; 4. Drying chamber; 5. Insulated drying shelves; 6. Solar panels; 7. Chimney; 8. Ash hole; 9. Drying chamber door; 10. Exhaust fan; 11. Accu; 12. Heat exchanger pipe Fig. 1 Design of double furnace type dryer with rice husk energy The dryer arrangement consists of two furnaces for directly burning rice husks and a drying chamber with six vertical shelves. At the bottom of the furnace, heat exchanger pipes are placed. Furnaces are placed on both sides of the drying chamber. Hot air in the drying chamber is obtained due to convection heat transfer from the heat exchanger pipe and conduction from the furnace. The drying chamber is isolated with 3 mm rubber insulating material and is equipped with an exhaust fan on the exhaust duct. The process of burning rice husks is assisted by the presence of air circulation holes on the walls of the furnace. The diameter of the furnace wall hole is 8 mm. This diameter is used because the resulting temperature pattern is more stable and the smallest, based on previous studies (Alit et al., 2021). The study evaluated the dryer's performance in drying white turmeric and compared it with sun drying. Evaluation based on drying temperature, moisture content of white turmeric, and drying rate. The drying time was set at 420 minutes, with the measurement of the moisture content carried out every 60 minutes. The mass of the sample is 4500 grams, distributed evenly on each shelf in the drying chamber. The sample mass of each shelf is 750 grams. For direct sun drying, use a sample of 1175 grams. Before drying, white turmeric is washed and sliced lengthwise with a thickness of 3 mm. The test uses a dryer design, as shown in Fig. 1, with the sample test method shown in Fig. 2. 1. Data logger; 2. Cup anemometer; 3. Furnace; 4. Rice husk; 5. Thermocouple K type; 6. Drying chamber; 7. Solar panel; 8. White turmeric; 9. Shelf 1; 10. Shelf 2; 11. Shelf 3; 12. Shelf 4; 13. Shelf 5; 14. Shelf 6 Fig. 2 White turmeric sample testing The research data measured were the ambient temperature, the temperature of the heat exchanger pipe, the temperature of each shelf exiting the drying chamber, the initial mass, and the dry mass of white turmeric. The moisture content, drying rate, and drying efficiency can be calculated based on these data. The mass of white turmeric includes the initial mass, mt (kg), and dry mass, mk (kg). The dry mass of white turmeric, mk (kg), was obtained by heating for 3 hours at a temperature of 105-110oC. The initial and dry masses were used to calculate the moisture content, Ka (%) (Henderson and Perry, 1976; Fridh et al., 2014; Hamdani et al., 2018). $Ka = mtm-tmk$ 100% (1) The drying rate, ṁp (kg/s) was calculated based on the ratio of the mass of evaporated water, mw (kg), to the drying time, t (hours) (Brooker et al., 1992; Nazghelichi et al., 2010). $\dot{m}m = m\ w\ t$ (2) mw was calculated based on the mass of white turmeric after drying mp (kg) and the initial mass of white turmeric, mt (kg). mw = mt – mp (3) The calculation of drying efficiency uses the ratio of the heat used for drying, Q (kJ), to the energy transfer from the air to the material being dried, q (kJ) (Çengel and Turner, 2004). η = 100% $Q\ m$ (4) Q (kJ) is the heat used for drying, as in Eq. (5). Q = Q1 + Q2 (5) Q1 is the heat to heat the material water (kJ). Q2 is the amount of heat evaporating the water (kJ) (Hamdani et al., 2018; Çengel and Boles, 2006). Cpb is the specific heat of white turmeric (kJ/oC), Tb is the temperature of white turmeric (oC), Ta is the ambient temperature (oC), and hfg is the latent heat of evaporation of water (kJ/kg). $Q1 = mt\ Cma(Ta - Ta)$ (6) $Q2 = mw\ hff$ (7) Based on Eq. (4), the energy transfer from the air to the dried material or q (kJ) is calculated using Eq. (8) (Incropera et al., 2006). $q = \rho t\ Vt\ Cmt(Tim - Tmtt)$ (8) ρu is the density of drying air (kg/m3), Cpu is the specific heat of the air (kJ/kg.oC). Tin is the inlet air temperature, and Tout is the outlet air temperature. 3. RESULTS AND DISCUSSION Initial measurement results show that white turmeric has a moisture content of 88%. Fig. 3 compares the moisture content of the drying process using a dryer and the sun. Moisture content (%) 0 100 200 300 Time (min) Ka direct sun Ka HX dryer 400 500 Fig. 3 The comparison of white turmeric moisture content (Ka) between direct sun drying and heat exchanger drying The decrease in the moisture content of the material in the use of hot air is faster than direct sun drying. Hot air is generated using a double furnace dryer and heat exchanger with rice husk energy. At minute 420, white turmeric's moisture content reached 35.88% in direct sun drying, while for hot air, it reached 2.7% for all samples. The moisture content in hot air is calculated based on the total initial mass of white turmeric, 4500 grams, and a total dry mass of 540 grams. White turmeric experienced a significant decrease in moisture content when using hot air for drying. There was a decrease in the mass of the material by 88%. The moisture content of white turmeric based on all samples was calculated every 60 minutes. At 60 minutes, it is 85.108%, 120 minutes is 78.681%, 180 minutes is 67.703%, 240 minutes is 47.317%, 300 minutes is 25.926%, 360 minutes is 9.09%, and 420 minutes is 2.7%. This result is in line with Sharma et al. (2021), which showed that hot air drying of turmeric sliced with a thickness of 3 mm required a shorter time than direct sun drying. Fig. 4 shows the distribution of moisture content and mass of white turmeric on each shelf in the drying chamber from drying with hot air. Slower drying occurs from 0 to 120 minutes. This follows the nature of rice husks. Namely, the combustion process begins with the evaporation of the moisture content of rice husks. Rice husk contains 8.8% moisture (Mhilu, 2014). The drying temperature increases as the rice husk turn into charcoal. The highest change in moisture content occurred in shelf 1 (ka- s1) followed by a rapid decrease in the mass of the material (ms1). The distribution of samples on each shelf is an initial mass of 750 grams with an initial moisture content of 88%. On-shelf 1, it was found that at 240 minutes, the moisture content of the material was zero, and the mass did not change, which was constant at 90 grams (ms1) until 420 minutes. On- shelf 1, it was also found that a large change in moisture content occurred from 120 to 180 minutes, from 37.9 % to 1.1%. A different phenomenon was found on the shelf above it. The moisture content of the ingredients on shelf 2 (ka-s2) at minute 360 is zero with a mass of 90 grams (ms2) and at minute 300 is 5.3% with a mass of 95 grams. On-shelf 3, the moisture content of the material (ka-s3) reaches zero at 420 minutes with a mass of 90 grams. Unlike what happened on shelves 4, 5, and 6, it was found that the moisture content of the material at the end of the test (420 minutes) was 3.2% (ka-s4), 4.3% (ka-s5), and 8.2%, respectively (ka-s6) with a final mass of 93 grams (ms4), 94 grams (ms5), and 98 grams (ms6), respectively. The drying time is shorter when compared to the study by Borah et al. (2015) drying slices of turmeric samples using a solar conduction dryer which takes 12 hours to effectively reduce the moisture content from 78.65% to 5.5%. 100 Moisture content (%) 90 80 70 60 50 40 30 20 10 0 0 100 200 300 400 Time (min) (a) 800 700 600 Mass (g) 500 400 300 200 100 0 ka-s1 ka-s2 ka-s3 ka-s4 ka-s5 ka-s6 500 ms1 ms2 ms3 ms4 ms5 0 60 120 180 240 300 360 420 480 Time (min) (b) Fig. 4 The comparison of the (a) moisture content (ka-s), (b) mass (ms) of white turmeric on each shelf in the drying chamber Differences in moisture content changes and material mass on each shelf follow the distribution pattern of hot air drying. The higher the drying temperature, the greater the reduction in moisture content of white turmeric, as shown in Fig. 5a. Shelf 1 has the closest position to the hot air source compared to shelf six, which is far away from the hot air source. This gives the impact of differences in changes in moisture content and mass of material. Based on the pattern of changes in moisture content, such as Fig. 4a, it was found that reaching the standard limit for the moisture content of dry white turmeric took a different time on each shelf in the drying chamber. This condition can be used as a reference for the drying time for each shelf. As in shelf 1, closest to the heat source, the highest drying temperature occurs, as shown in Fig. 5b. The average drying temperature on shelf 1 (Ts1) is 119.12oC with a range of 84.70- 142.78oC. The highest temperature on shelf 1 compared to shelves 2, 3, 4, 5, and 6 with an average of 104.99oC (55.9-124.76oC), 93.24oC (48.02- 120.79oC), 79.99oC (37.47-112.79oC), 74.69oC (41.43-95.44oC), and 73.65oC (36.15-103.22oC) respectively. The higher the drying temperature, the faster the white turmeric will decrease in moisture content. This impacts the drying process of white turmeric on shelf one, which takes more time than the shelf above. This research is in line with Waheed and Komolafe (2019); Dasore et al. (2020) that an increase in temperature causes a decrease in drying time. In contrast, what happened to direct sun drying with a test time of 420 minutes was only able to reduce the moisture content of white turmeric by 47.826%. This is a result of the drying temperature not optimal. Drying only uses ambient temperature with an average of 30.91oC (29.48-32.06oC). The lower the temperature, the longer the operating time (Bevington and Robinson, 2003). The increase in the drying temperature causes the drying rate to be faster. 160 140 Temperature (oC) 120 100 80 60 40 20 0 0 20 Temperature (oC) 40 60 80 100 Moisture content (%) (a) 0 60 120 180 240 300 360 420 Time (min) (b) Direct sun S1 S2 S3 S4 S5 S6 Ta Ts1 Ts2 Ts3 Ts4 Ts5 Ts6 Tp Tout Fig. 5 (a) The comparison of white turmeric moisture content and (b) drying temperature distribution pattern The comparison of drying rates using sun and hot air per hour is presented in Fig. 6a. In this study, it was found for a test time of 420 minutes that the drying rate using the sun (mp-direct sun) was much slower with a high-moisture content compared to using hot air. It is strongly influenced by the drying temperature as shown in Fig. 6b. Higher temperatures affect faster drying rates. The drying rate on shelf 1 (mp1) is the fastest because the drying temperature is the highest (S1). The farther the drying shelf is from the heat source, the slower the drying rate. In the use of hot air, the slowest drying rate occurs on shelf 6 (mp6). The drying rate after reaching the peak then decreases as the moisture content decreases. On-shelf 1, the drying rate (mp1) peaked at 180 minutes. On shelves 2 and 3 (mp2 and mp3) at 240 minutes, and shelves 4, 5, and 6 (mp4, mp5, mp6) at 300 minutes. Free moisture due to sensible heat transfer to the turmeric sample decreased after the peak drying rate was reached (Sharma et al., 2021). The high drying rate occurs when the moisture content of white turmeric is still high, as in Fig. 6c. It was found that the drying rate is directly proportional to the moisture content. As the moisture content decreases, the drying rate also decreases. For the test time of 420 minutes, the initial moisture content of the turmeric sample as a whole was 88%, decreased to 2.7% in direct proportion to the drying rate, namely the average of 145.67 g/h decreased to 6.5 g/h. This is in line with the research of Lakshmi et al. (2019) that the drying rate is relatively higher at higher moisture content. 400 mp-direct sun mp1 Drying rate (g/h) 300 mp2 mp3 mp4 200 mp5 mp6 100 0 0 60 120 180 240 300 360 Time (min) (a) Temperature (oC) Drying rate (g/h) 160 140 120 100 80 60 40 20 0 0 100 400 350 300 250 200 150 100 50 0 0 20 200 Drying rate (g/h) (b) 40 60 300 80 Moisture content (%) (c) 420 Direct sun S1 S2 S3 S4 S5 S6 400 Direct sun S1 S2 S3 S4 S5 S6 100 Fig. 6 The comparison of drying rate with (a) time, (b) temperature, and (c) moisture content The slow drying rate of white turmeric with still high-moisture content occurs in direct sun drying. At the end of the test (420 minutes), the drying rate was 30 g/h. The moisture content was 35.88% with an average drying temperature of 30.91oC. In drying white turmeric with hot air for shelf 1, it was found that the drying process was sufficient for a maximum of 180 minutes. At that time, the drying rate reached 54 g/h, moisture content 1.1%, and mass 91 g, with an average drying temperature of 119.12oC. On-shelf 2, the drying process can be carried out for 300 minutes. In this condition, the drying rate reached 16 g/h, moisture content 5.3%, and mass 95 g, with an average drying temperature of 104.99oC. On-shelf 3, the drying process can be carried out for 300-360 minutes. In this condition, the drying rate reaches 30-7 g/h, moisture content 9.1-2.2%, mass 99-92 g, with an average drying temperature of 93.24oC. On shelves 4 and 5, the drying process can be carried out for 360-420 minutes. In this condition, each drying rate reached 32-9 g/h and 40-12 g/h, moisture content 11.8-3.2% and 15.1-4.3%, mass 102-93 g and 106-94 g, with an average drying temperature of 79.99oC and 74.69oC. On-shelf 6, the drying process can be carried out for 420 minutes. In this condition, the drying rate reached 16 g/h, moisture content 8.2%, and mass 98 g, with an average drying temperature of 73.65oC. The results of the dry moisture content test follow the required standards. During the test, there was no additional mass of fuel, so the drying temperature changed after burning rice husks that burned out longer. The moisture content of dried turmeric has different standards or requirements. Singh et al. (2010) state that the safe limit for storage is 6%. The dry moisture content for turmeric slices with a thickness of 3 mm dried using a dryer is 6.9%, and the maximum US trade quality standard is 9% (Manoi, 2013). The study by Sharma et al. (2021) showed the moisture content of sliced turmeric with a thickness of 3 mm, which was dried using hot air within 2.5 hours, was 3.33%. Changes in moisture content were followed by changes in dryer efficiency, as presented in Fig. 7. 50 Efficiency 90 Moisture content 80 Dryer efficiency (%) 40 70 30 60 50 20 40 30 10 20 10 Moisture content (%) 0 0 60 120 180 240 300 360 420 Time (min) (a) Efficiency Temperature 120 Dryer efficiency (%) 110 100 90 80 70 60 50 40 30 20 Temperature (oC) 10 0 10 0 60 120 180 240 300 360 420 Time (min) (b) Fig. 7 Distribution pattern of dryer efficiency, moisture content, and temperature against time Fig. 7 shows the dryer's efficiency during the testing time of the white turmeric sample and is calculated according to the moisture content measurement carried out every 60 minutes. Fig. 7 also shows the effect of temperature on dryer efficiency. The efficiency of the dryer decreases following the decrease in the moisture content of white turmeric. Dryer efficiency can reach 32.81% at minute 60. This is due to the moisture content in white turmeric being still high. At the end of the test, at minute 420, the efficiency reached 4.06%. This follows Djaeni et al. (2019), very 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. In the study, it was found that for 240 minutes, an increase in drying temperature was seen, followed by a decrease in drying efficiency. For 240 minutes, there was a decrease in the high moisture content of white turmeric by 43.98%, from an average of 88% to 38.71%. Drying efficiency decreased due to reducing the high moisture content in white turmeric. Different that happened from 240 minutes to 420 minutes. A decrease follows the drying temperature decrease in the dryer's efficiency. This condition occurs because the heat used for drying is more wasted due to the smaller moisture content in white turmeric that has undergone evaporation. The decrease in moisture content of white turmeric from 240 to 420 minutes was relatively small at 6.74%, namely from an average of 38.71% to 2.61%. Efficiency decreases during the drying process (Balbine et al., 2015). The decrease in drying temperature occurred because, during the drying process, the amount of rice husk was constant in both furnaces, each 17.5 kg or 35 kg. Testing on white turmeric using a desiccant design from the research of Alit et al. (2021) showed that the dryer's performance showed good results. This can be seen from the short drying time for white turmeric samples on the scale of small farmers, which is 4500 grams. 4. CONCLUSIONS A double furnace-type hot air dryer and heat exchanger with rice husk energy were applied to dry white turmeric. White turmeric dried using hot air gives better results than sun drying. The drying process was carried out with white turmeric sliced 3 mm thick with an initial moisture content of 88% with a drying time of 420 minutes. • Drying with hot air can achieve an overall final moisture content of 2.7%. While the final moisture content using sun drying is 35.88%. • The sun-drying temperature, with an average of 30.91oC, is much lower than the hot air dryer, which reaches an average of 90.95oC. • On each shelf in the drying room, there is a difference in drying time to reach the final moisture content of white turmeric. The moisture content on shelf one within 180 minutes reached 1.1% with an average drying temperature of 119.12oC. The longest occurs on shelf 6, which is within 420 minutes. The moisture content reaches 8.2% with an average drying temperature of 73.65oC. • The highest drying efficiency occurred at the beginning of the drying process, namely 32.81%, and the lowest occurred at the end, 4.06%. This occurs due to the influence of the high initial moisture content. During drying, the moisture content of the material evaporates, which impacts the energy absorption process by white turmeric from the dryer. • Using 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. • Further research is needed to reduce the relatively high fluctuation of drying temperature by adding a thermostat and exhaust fan. ACKNOWLEDGEMENTS The authors wish to acknowledge DRPM, the Ministry of Education, Culture, Research, and Technology, the Republic of Indonesia, for funding through the 2022 PTUPT research scheme with contract number 1256/UN 18.L1/PP/2022 for the second year of research. The author also wishes to thank the Department of Mechanical Engineering, University of Mataram, for facilitating the implementation of this research. 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