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Solar Dryer Applications for Cassava Slices Drying

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Abstract. In this paper, a newly-designed solar dryer was used for drying of cassava slices. Cassava from local market were peeled, washed, and cut into slices with approximately 1-2 mm in thickness. Using the oven method, it is found that the initial moisture content of cassava slices used in this experiment was 54,25% w.b. Drying experiment was carried out from 09.00 A.M. to 05.00 P.M. Several analysis were conducted, namely the temperature, relative humidity, and solar radiation profiles analysis, the drying curve analysis, drying rate analysis, and the effectiveness factor analysis. It is found that the temperature and solar radiation values were maximum at 11.00 A.M., while at the same time the value of ambient relative humidity was minimum. Only cassava slices dried at the 1st tray (top tray, 13,1% w.b.) could satisfy the maximum moisture content of cassava slices governed by Indonesian Standardization Body, which is 14% w.b. Drying rate at the first tray was the fastest and drying of cassava slices happened at the falling rate period, indicated by the decreasing values of drying rate. The effectiveness factor varied between 0,68 – 2,59 which indicated that the solar dryer used in this experiment was more efficient than the open sun drying. The dryer efficiency from the three drying trays were ranged from 0,7% to 2,72%, which were lower than the values found in several literatures about solar dryer.

INTRODUCTION

According to the FAO, Indonesia ranks fourth in the cassava production in 2017, with 19,046 metric tonnes of cassava production.[1] In Indonesia, cassava is the fourth most important crop after paddy, maize, and soybean.[2] It is grown in every province of Indonesia, with Java and Sumatra as the main production areas. The main advantage of cassava is that it can be grown on almost everywhere, even on barren lands, because cassava does not need many requirements to grow.[3] Generally, cassava is grown by small-scale farmers located right up to cassava-processing factories which are usually close to the cultivating area.[4] Although the production quantity is relatively high, the applications of cassava and its derivative in Indonesia is still limited. One of the promising cassava products is dried cassava or cassava slice (commonly known as "gaplek" in Indonesia). Dried cassava is mostly used for cattle food, made into cassava flour, or being made into syrup.[5] However, freshly harvested cassava has relatively high moisture content, ranged from 40% to 70%.[3] Therefore, improper drying and storage will spoil the cassava and make it susceptible to molds or bacteria.[5]

Drying is a highly energy-intensive process, accounting for 10-20% of total industrial energy usage in most developing countries. This is because a certain amount of latent heat of evaporation must be generated to remove water from the dried product.[6] Drying techniques may vary among farmers, ranging from conventional sun drying to artificial drying. Drying will allow farmers to store cassava slices for a longer period by reducing the rate of biological degradation. Another benefit of drying is considerable weight and volume reduction of cassava slices, which helps simplify the packaging and save storage and transportation costs.[4] According to the Indonesian Standardization Body, the maximum allowable moisture content for cassava slices for safe storage is 14% w.b.[7]

The most popular drying method used by cassava farmers in developing countries is conventional open sun drying. It is simple to perform, safe, and most importantly, it's cheap and affordable by local farmers. Although it does not require any additional energy, it greatly depends on the weather, therefore causing fluctuations in drying time.[8] It will

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also cause losses in both the quality and quantity of the dried product due to contamination by dirt, dust, and infestation by insects, rodents, and animals.[9] However, using artificial dryer (require electricity and fuel) will consume more energy, requires more cost, and causes pollution.[2] Therefore, solar dryer is a promising solution to overcome the weaknesses of open sun drying and artificial drying. The differences between solar dryer and open sun drying are the enclosure of the dried products and the direct or indirect production of a solar-heated airflow. Compared to open sun drying, solar dryer is generally faster, more efficient, more hygiene, and able to reduce crop loss.[10]

There are several benefits that can be obtained by using solar dryer, such as improving the quality of dried products, shortening the harvesting period, which enables the soil to be prepared for cultivation of other crops, extending the drying season through successive harvests, greater income for the farmers because of more marketable crops, additional cost involved in installing solar dryer can be returned by the increased profits, and lastly, the availability of solar energy, operational marketing, and the economical reasons offer a good opportunity for using solar dryer.[11] Solar dryer has been widely applied to dry various crops and products such as medicinal plants,[12] powders,[13] pear,[14] grape pomace,[15] banana,[16] potato slices,[17] lumbers,[18] and mango.[19] However, only a few literature can be found about the application of solar dryers for cassava drying. The types of solar dryer used are varied, such as forced-convection cabinet dryer equipped with furnace,[8] natural convection mixed-flow solar dryer,[20] and natural convection indirect solar dryer[21]. It can be concluded from those researches that solar dryers are able to reduce cassava slices' moisture content to the safe level, although the drying time varies between three hours to three days, with natural solar dryers require longer drying time.

Based on the literature review, it is shown that the design of solar dryer greatly affects the drying process. In this paper, a newly-designed solar dryer was used to dry cassava slices. The type of the solar dryer was forced-convection, integral solar dryer. To assess the performance of the dryer, five analyses were conducted, namely the temperature, relative humidity, and solar radiation profile analysis, moisture content analysis, drying rate analysis, the relation between drying rate and moisture content, and the effectivity factor analysis. Cassava slices were also dried using open sun drying method as a comparison to solar dryer method.

EXPERIMENTAL PROCEDURE

Figure 1 shows the side view of the solar dryer used in this experiment, while Figure 2 shows the inner view of the solar dryer, as well as the drying trays. The solar dryer is box-shaped with dimensions of 90 cm in length, 90 cm in width, and 120 cm in height. The outer part of the solar dryer is covered by aluminum with 1 mm in thickness. Aluminum was chosen because of its good heat conductivity, relatively light, strong, and easy to obtain. The inner frame of the solar dryer is made from stainless steel 1,2 mm thick. The inside walls of the solar dryer are also covered by glass wool. This solar dryer only utilized solar energy as its main heat source and relied on the high conductivity of aluminum and stainless steel to store heat and conducting heat from outside the dryer to the inside. An acrylic panel with the dimensions of 90 x 90 x 0,5 cm in length, width, and thickness, respectively, is placed on top of the dryer which acts as the solar radiation absorber. Acrylic has good absorbability to sun radiation, light-weighted, and much cheaper compared to glass. This acrylic panel is inclined so that the dryer position can be adjusted according to the direction of the sun during the drying process. To ease the transport and movement of the dryer, four wheels are installed at the bottom corner of the solar dryer.

There are three drying trays inside the dryer, each has a size of 80 cm x 80 cm of length and width, with 27,5 cm of space between each tray. The trays are made from perforated plate so that the drying air could pass through each tray. The edge frames of each tray are made from aluminum and at the left and right side of each tray, tray holders made from aluminum are installed to place the tray. At the top of the dryer, a chimney is installed so that the humid air inside the dryer can flow outside. To help distribute the heat more evenly inside the dryer and to blow out the humid air, a blower (Figure 3) is installed at the bottom of the dryer, which will blow the drying air upwards. At the bottom inner side of the dryer and the top of the dryer just below the chimney, temperature and relative humidity indicators are installed. Temperature indicators are also installed on each tray, specifically at the aluminum holders where the tray was placed. A control panel is installed on the left side of the solar dryer. This control panel functions as the on/off mechanism of the blower as well as to display the values of temperature and relative humidity obtained from the indicators installed on several locations inside the dryer, using a touchscreen LED, as shown in Figure 4.

FIGURE 1. Side view of the solar dryer

FIGURE 2. Drying trays and inside part of solar dryer

FIGURE 3. View of blower at the bottom of the dryer

FIGURE 4. Inside view of the control panel, along with touchscreen LED

All drying experiments were performed in the Laboratory of Chemical Engineering Department, Diponegoro University, Semarang, Indonesia. The only material used in this experiment was cassava tubers, obtained from the local market. Cassava tubers were peeled, washed, and then cut into small slices with 1-2 mm thickness. The initial moisture content of cassava slices was determined using the AOAC method, with a value of 54,25% wet basis.[22] The tools needed were digital weigher, temperature and Relative Humidity meter (@Krisbow S000052505), solar intensity meter, anemometer, and several perforated containers to weigh the cassava slices. There were 2 drying methods performed in this experiment, namely open sun drying and solar drying methods. For open sun drying, 200 grams of wet cassava slices were placed on the perforated container and left under the sun for eight hours, from 09.00 A.M. to 05.00 P.M. The cassava slices was weighed once every 60 minutes. The temperature and relative humidity near the open sun drying location (which considered to be the ambient condition) were also measured.

For the solar drying method, before the drying process began, the dryer was prepared first by plugging the power plug into the electric socket, then turn on the switch inside the control panel. The touchscreen LED inside the panel will boot up and the blower will turn on. After the touchscreen LED started displaying values, the dryer was ready to be used. While waiting for the dryer to be ready, 600 grams of cassava slices were weighed, divided into three parts containing 200 grams for each tray, and then were spread inside the dryer. The drying process was performed from 09.00 A.M. to 05.00 P.M. The cassava slices were weighed every one hour using digital weigher. Every hour, the data displayed at the touchscreen LED were recorded, except for relative humidity values of each tray, which have to be measured using relative humidity meter. The solar intensity was measured once per hour using solar intensity meter by placing it above the acrylic panel and by directing its sensor towards the sun so more accurate solar intensity readings could be obtained. During the drying process, the solar dryer's position was adjusted following the direction of the sun to maximize the heat gain.

DATA ANALYSIS

After the drying was ended, the recorded data were used to perform several analyses, which consists of:

Moisture Content Analysis

Based on the measurements of cassava flour's weight every hour, the moisture content of cassava slices at any given time can be determined using Equation 1.[23]

$$X = \frac{m_t}{m_t + m_d} \tag{1}$$

Where X is the moisture content, m_t is the mass of cassava flour at any given time, and m_d is the mass of dry cassava flour

Drying Rate Analysis

Aside from being used to determine the moisture content of cassava flour, the cassava flour's weight can also be used to determine the drying rate (R_d, in gram/minutes), by dividing the weight difference (m_t-m_d) at any given time interval (t), using Equation 2.[23]

$$R_d = \frac{m_t - m_d}{t} \tag{2}$$

Effectivity Factor Analysis

The effectivity factor (*ef*) can be determined by dividing the drying rate obtained from solar dryer (R_{dso}) and the drying rate obtained from open sun drying (R_{dsu}), as shown in Equation 3.[23]

$$ef = \frac{R_{dso}}{R_{dsu}} \tag{3}$$

Dryer Efficiency Analysis

The cassava slices' weight and solar intensity data can be further processed to determine the energy efficiency of the process, as shown in Equation 4.[23]

$$\eta_d = \frac{m_w h_{fg}}{IAt + E} x100 \tag{4}$$

Where η_d is the energy efficiency, m_w is the mass of evaporated water (kg), h_{fg} is the latent heat of vaporization of water (kJ/kg), I is the solar intensity (W/m^2), A is the area of solar collector (m^2), t is the drying time (s), and E is the energy consumption of blower (kWh).

RESULTS AND DISCUSSION

Analysis of Temperature, Relative Humidity, and Solar Intensity Profiles

The temperature, relative humidity, and solar intensity data obtained from measurements during the drying of cassava slices using solar dryer and open sun drying method are presented in Figure 5. It can be seen that the ambient temperatures ranged from 29,5 to 44 ºC. The temperatures near the dryer outlet were ranged from 30,2 to 73,9 ºC while the temperature at the dryer inlet (at the blower) ranged from 30 to 49,5 ºC. Due to the dryer's design, the upper part of the dryer will always hotter than the bottom part. At 11.00 A.M., the value of inlet temperature, outlet temperature, and ambient temperature was at its highest. After 00.00 P.M., the temperatures began to decrease steadily. Similar results were found on other researches about solar dryer.[23,24] The temperatures at both dryer inlet and outlet were always higher than ambient temperature, indicating that the drying chamber is well insulated.[14] The solar intensities are varied between 111 to 1110 W/m^2. The maximum solar intensity recorded was 1110 W/m^2 at 11.00 A.M.. However, certain research has stated that the recorded average solar radiation in Semarang is 1536,63 W/m^2.[25] This might be caused by different measurement times, geographical position, and weather conditions during the measurement. The ambient RH recorded in this experiment were ranged from 29,2 to 63,88%. It can be seen from Figure 3 that the RH profile was inversely proportional to the dryer temperature. When the drying temperature was increased, more water will be evaporated from the cassava slices. This evaporation will reduce the moisture content, which in turn will also reduce the value of relative humidity.[26]

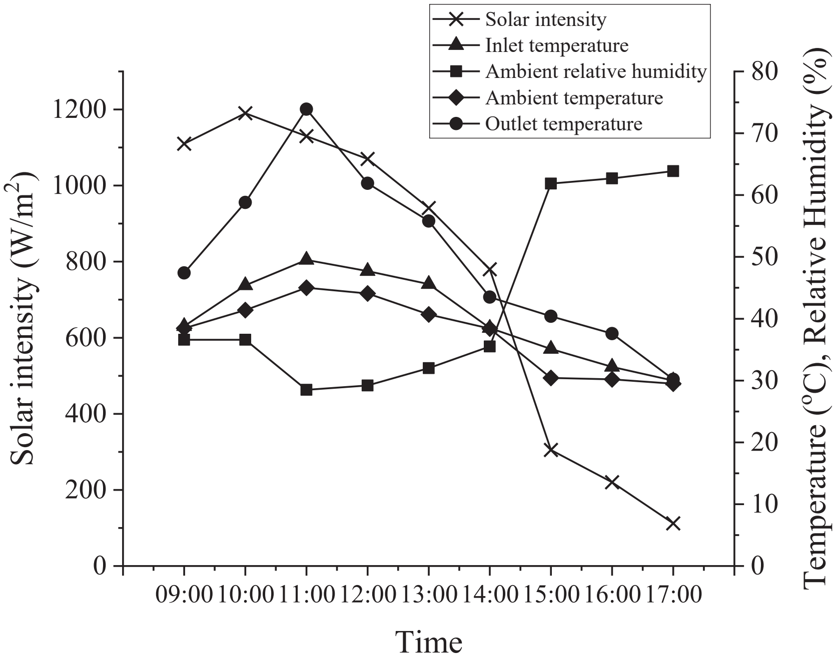

FIGURE 5. The profiles of temperature, relative humidity, and solar intensity during drying of cassava slices

Analysis of Moisture Content Curve

Figure 6 shows the moisture content curve versus time on the solar dryer at each tray and open sun drying method. It can be seen from the graph that moisture reduction at the first tray was the fastest, followed by drying at the second tray, at the third tray, and open sun drying, which was the slowest. The final moisture content of cassava slices dried at the first tray, second tray, third tray, and using open sun drying method was 13,1%, 20,92%, 27,78%, and 32,32%, respectively. Based on this results, only drying at the first tray give the desired final moisture content, according to the Indonesian Standardization Body, which is 14% w.b.[7] The first tray is located at the top and the heat absorbed by the solar collector will be utilized first by the first tray, then the second tray, and finally the third tray, therefore the first tray is hotter compared to the others and has the fastest moisture reduction.[4,12,16,27] Compared to the drying process using the solar dryer, moisture reduction using the open sun drying method was slower. This is because the enclosed design of the solar dryer enables the dryer to store heat so that more water can be evaporated. The dryer's inner walls were mostly built using stainless steel, which has good heat conductivity. Also, during the open sun drying, the cassava slices were constantly exposed to humid winds and dust, which might slow down the moisture reduction process.[23,28] It is also shown that the moisture content reduction at the initial phase is faster compared to the final phase. This happened mainly because of the diffusion process. Initially, the moisture from the cassava slices'surface is evaporated. As the drying process continues, the moisture migrates from the inner to the surface of the product. This indicates that the drying of cassava slices happened at the constant and falling rate periods.[28]

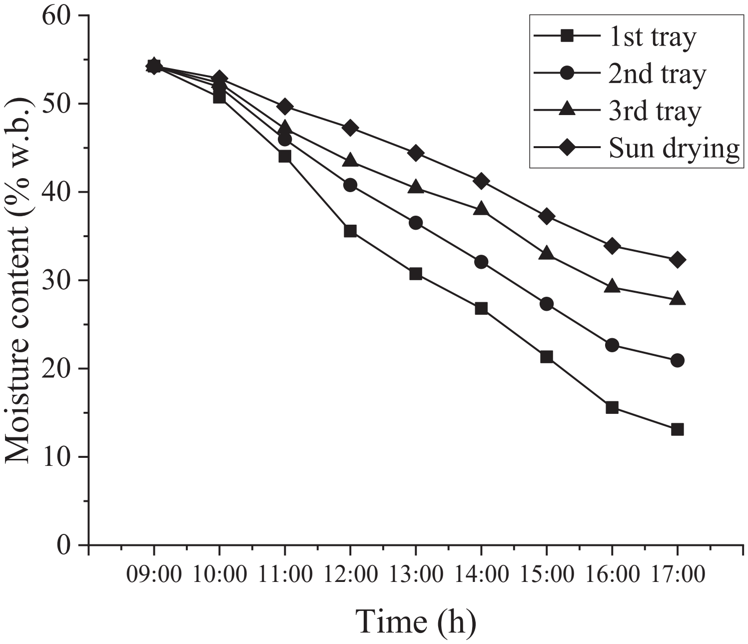

FIGURE 6. Moisture content curve of cassava slices dried using solar dryer and open sun drying

Drying Rate Analysis

The drying rate is defined as the amount of water evaporated at a certain amount of time. Figure 7 shows the drying rate of cassava slices dried using the solar dryer and open sun drying. The maximum drying rate on both solar dryer and open sun drying were recorded at 11.00 A.M. when the solar intensity was at its highest, in which the values were 0,0222; 0,0209; 0,0188; and 0,0123 kg/hour for the first tray, second tray, third tray, and open sun drying, respectively. It is shown that the drying rate at the first tray is the fastest, followed by drying rate at the second tray, at the third tray, and open sun drying. This happens because the temperature at the first tray is the highest, therefore the drying process is faster than the lower trays, as the heat will be utilized first by the first tray and by the time the heat circulates through the second and the third tray with the help of blower, the drying air is already more humid compared to the first tray.[29-31] Similar drying rate trends are also found on grape pomace drying using a double-pass solar collector,[15] cashew drying using hybrid solar dryer,[23] and carrot drying using a solar dryer with a double-pass solar collector.[32]

It can also be seen from Figure 7 that the drying rate is fast at the initial phase of the drying, then gradually decreasing until it reaches a constant value. During the initial phase of drying, the moisture content of cassava slices are still high, especially the free moisture content located at the surface and the outer side of cassava slices. As the drying process continues, the moisture will evaporate, leaving the bound moisture content, which is located at the inner surface of the cassava slices. Bound moisture content is harder to remove due to the resistance of cassava slices' inner cells against water diffusion. This will cause the drying rate to decrease until it reaches a constant value.[33] Therefore, it can be concluded that cassava slices drying happens at the falling rate period, indicated by the decreasing value of drying rate, while constant rate period occurs very fast, which is during the initial phase of drying (from 09.00 A.M. to 11.00 A.M.).[6]

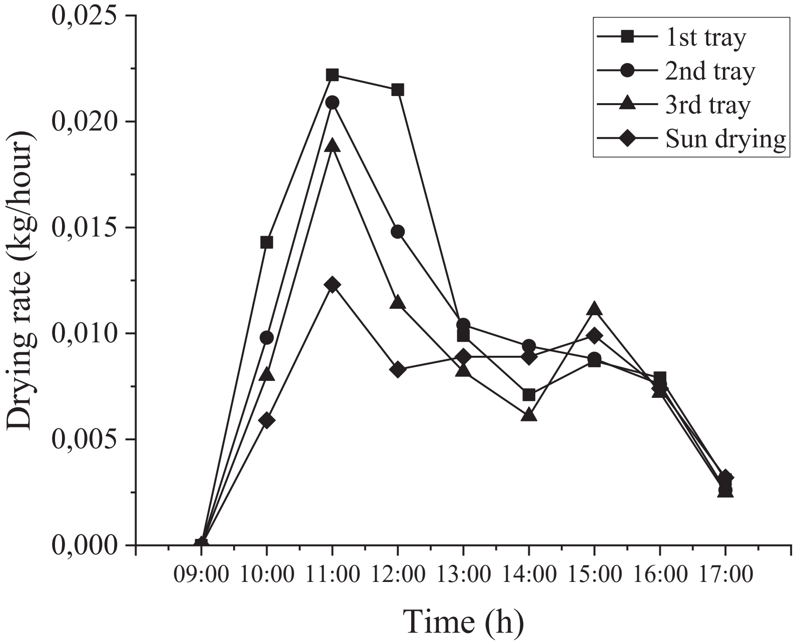

FIGURE 7. Drying rate curve of cassava slices dried using solar dryer and open sun drying

Effectiveness Factor Analysis

The effectivity of solar dryer compared to open sun drying can be determined by dividing the drying rate of solar dryer and drying rate of open sun drying. Figure 8 shows the diagram of effectiveness factor of the solar dryer at the three drying trays versus drying time. From the three drying trays, the effectiveness factor value ranged from 0,68 – 2,59. The highest effective factor of the first, second, and the third tray was 2,59; 1,78; and 1,53, respectively. The effectiveness factor values at the three trays are high during the initial phase of drying, then gradually decrease as drying progressed.[23] It can be seen from the graph that the highest value of effectiveness factor was recorded during drying at 00.00 P.M. for the first and the second tray, while at the third tray the maximum effectiveness factor occurred at 11.00 A.M. Therefore, drying at the first tray is the most effective, followed by the second and the third tray. Overall, the solar dryer is more effective for drying cassava slices compared to the open sun drying.[34]

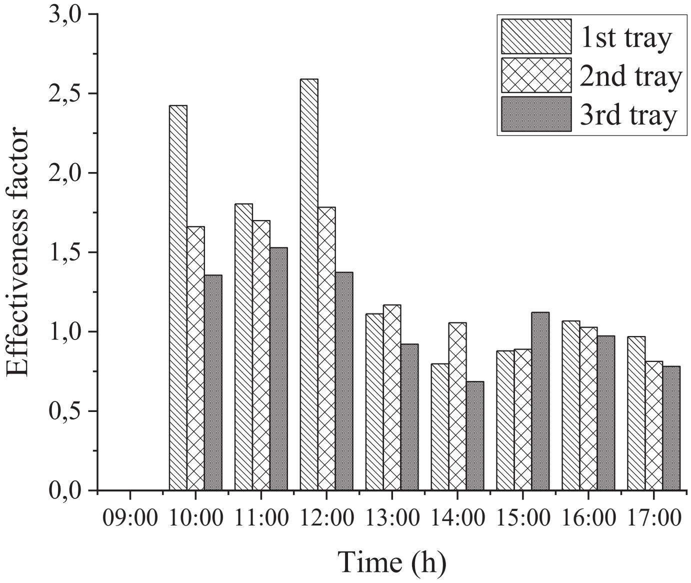

FIGURE 8. Effectiveness factor of solar dryer at different trays

Dryer Efficiency Analysis

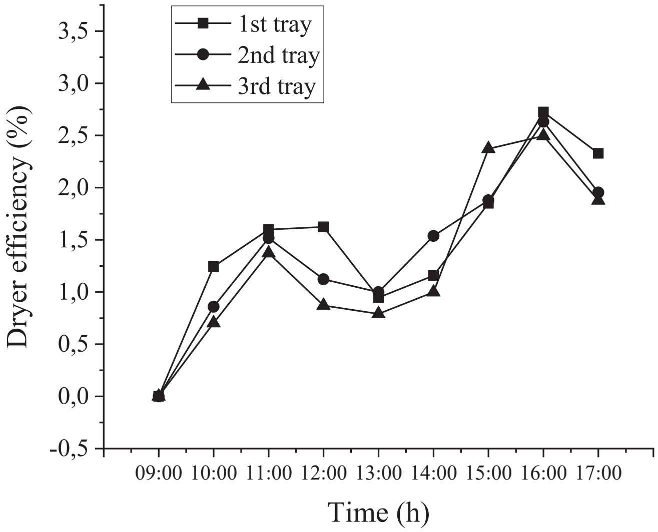

FIGURE 9. Solar dryer efficiency at different trays

Figure 9 shows the efficiency of the solar dryer at different trays. The efficiency ranges of the first, second, and the third tray were 0,94%-2,72%, 0,86%-2,63%, and 0,7%-2,49%. The maximum efficiency values occurred at 04.00 P.M. Overall, the first tray is the most efficient, followed by the second and the third tray. However, compared to several studies about solar dryer application for food crops, dryer efficiency values found in this experiment is much lower. The efficiency values of solar dryer are on the range of 2%-40,6% for cassava,[2] 30%-33,8% for mango drying,[19] 2%-4% for cashew drying,[23] and 14%-28% for ginger drying.[24] This might be possible because during the drying process, the dryer received a lot of heat energy from the sun (thanks to the wide solar absorber and the stainless steel wall inside the dryer which helped generate heat), but the usage was not efficient. Each tray contains 200 grams of cassava slices, which possibly contain too few moistures in respect to the energy supplied by the dryer. Therefore, the amount of energy required to dry the cassava slices are too few compared to the total energy supplied by the solar dryer, which may be the reason why the efficiency values are low.

CONCLUSIONS

In this paper, a newly-designed solar dryer was introduced and was applied for cassava slices drying, with several analysis performed to assess the solar dryer's performance. The profiles of temperature, relative humidity, and solar intensity were dependant on weather conditions, geographical location, and measurement time. The fastest drying occured at the first tray of the solar dryer, and only the final moisture content obtained from the first tray that was able to meet the requirement of cassava slices' maximum moisture content according to the Indonesian Standardization Body, which is 14% w.b. Drying rates of all drying modes were high during the initial phase of the drying, then gradually decrease until it reached constant value, indicating that cassava slices drying mostly took place at the falling rate period, with only a short time drying did take place on the constant rate period. Compared to the open sun drying, the solar dryer was more effective. However, compared to the other solar dryer studies, the efficiency of solar dryer found in this experiment was too low. Therefore, further optimization to the dryer or the drying methods and procedure is required to achieve more efficient drying process.

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