Drying Characteristics of Cacao Beans using Modified Solar Tunnel Dryer Type Hohenheim

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Abstract – Drying cacao has been conducted by open-sun drying systems by farmers worldwide. To improve the cacao drying, the use of solar dryers can be applied. The objective of this study was to evaluate the drying characteristics of using a modified solar tunnel dryer type Hohenheim in drying cacao. As a comparison, the sun-drying method was also conducted. The parameters observed were temperature, relative humidity (RH), weight loss, moisture content, fat content, hardness, and drying rate. Results showed that the average temperature of the Hohenheim dryer was higher at about 10°C than the ambient temperature. However, the Hohenheim dryer's drying temperature fluctuated due to the oscillation of solar irradiation. The drying process took time for 12h in 2 days. The humidity in the drying chamber was high, above 50%, representing that the dryer needed additional fans to improve its air circulation. The final moisture content of cacao dried using Hohenheim dryer and sun-drying was 12.7 and 17.4%, respectively. The drying rate of cacao dried using a Hohenheim dryer was double that of sun-drying. Therefore, the dryer can speed up the drying time and protect the cacao from contamination.

Keywords: Cacao beans; Drying; Type Hohenheim; Solar tunnel dryer.

Introduction

In Aceh province, the northwestern end of Sumatran Island, Indonesia, the government put cacao as a potential product to support the district's economy since it is distributed in about 87% of its area (20 out of 23 sub-districts). Thus, cacao is important to people's economy since many farmers depend on this product for their income. However, the main problems Aceh farmers face are low productivity and quality, including low adapted technology, especially in drying cacao. Primary processing of cacao beans, from the farmer's point of view, is time-consuming and challenging work because it consists of a long process that includes harvesting, gathering the ripe fruit, fruit opening, removing the beans, fermenting the beans and drying the beans (Guda et al., 2017). We consider the sun-drying method applied by our farmers for drying cacao, which is believed to influence the low quality of the cacao beans, for instance, the use of the road part as a drying bed.

The Sun-drying method, the oldest drying method used by humans, has many disadvantages, such as a long time and need large area. Ahmed et al. (2013) stated that shorter drying times are very important to reduce the risks of food spoilage or mold growth in the drying process. According to Fagunwa et al. (2009), properly dried cacao beans, usually at about 6-8% moisture content (wet basis), have reduced acidity and are characterized by the familiar 'chocolate' brown color. The quality of products from cacao beans, especially chocolate and beverages, is a function of how they are processed (Chinenye et al., 2010), including the drying process.

The quality of cacao could be improved by drying technology. Drying may be carried out naturally using solar or artificial energy in greenhouses (Deus et al., 2018) or forced-air drying, depending on some socio-economic considerations and prevailing climatic conditions (Fagunwa et al., 2009). Drying and fermentation are essential in forming flavor and taste (Dina et al., 2015). However, concerning that local farmers are characterized by small-
scale farmers with low education and low technology adaptation; the new appropriate drying technology should meet these conditions. The drying technology should be simple, easy to use and handle, cheap, and use renewable energy. It is important also that the dryer cost is affordable for the farmers.

Solar drying is one of the most efficient and cost-effective, renewable, and sustainable technologies to conserve agricultural products in Asian and sub-Saharan African (SSA) countries (Mewa et al., 2019; Udomkun et al., 2020), especially under tropical climates (Simo-Tagne and Ndi-Azese, 2021). In Thailand, a study on drying Andrographis paniculate was conducted (Srisittipakakan et al., 2012). The dryer could be developed with eco-friendly, low-cost, sensible heat storage (Sekhar et al., 2021) and an indirect two-stage solar tunnel dryer (Getahun et al., 2021). The type Hohenheim solar tunnel dryer was designed at a low cost (Green and Schwarz, 2001). Previous studies had been done on the performance of a modified type Hohenheim solar tunnel dryer in drying pliek-u (Khathir et al., 2015), red ginger (Mentari et al., 2017), red chili (Ridwan et al., 2017), coffee (Hardi et al., 2019), elephant ginger (Khathir et al., 2020), and oyster kerupuk (Khathir et al., 2021). Therefore, this study aims to evaluate the performance of modified type Hohenheim solar tunnel dryer in drying cacao beans. It is expected that the dryer can be used as an intermediate technology for farmers to improve the cacao beans quality.

Materials and Methods

The cacao fruits were collected from local farmers in Pidie Regency, the province of Aceh, Indonesia. The fruits were opened using a knife to get the wet cacao beans. Then, the wet beans were dried under two methods, the sun-drying method (Fig.2a) and the modified type Hohenheim solar tunnel dryer (Fig. 2b). The sun-drying method was conducted by spreading the wet beans on the black plastic sheet. The drying process was conducted until the final moisture of cacao beans was 14%, intermittently during the day from 8.00 am to 17.00 pm.

Before the treatment, the initial moisture of wet cacao beans was determined. During the drying process, some parameters observed were temperature and relative humidity in the drying chamber and weight loss of samples at intervals of 1 hour. After drying, the quality of cacao beans, including moisture, fat content, and hardness, was evaluated. The research procedure can be seen in Fig.1.

![Figure 1. Research procedures.](image-url)

A modified type of Hohenheim solar tunnel dryer (as seen in Fig. 2) was designed based on the solar tunnel dryer built at the University of Kassel in Germany (Green and Schwarz, 2001). The length of the dryer is 6m, the width is 2m, and the height above the ground is approximately 0.8m. About 3 fans of 12V 0.2A DC with a diameter of 12cm were installed to flow fresh air at a rate of 2 m/s during the drying process. A 50WP solar panel was installed to generate electricity. The dryer uses a transparent cover from a plastic sheet to generate the heat following the greenhouse effect mechanism. A solar collector is integrated in to the drying chamber with a fabricated black-painted corrugated zinc absorber. The ratio area of the drying chamber and absorber area was 1:1.

The moisture content of cacao was investigated under the oven method with circulating air at a temperature of 105°C until constant weight (AOAC, 1995). The moisture contents in the wet basis (MCwb) and dry basis (MCdb) were calculated using Eq. 1 and 2, where $m_1$ is the initial weight and $m_2$ is the constant weight. The
drying rate (R) is defined as the ratio of moisture removed for each kg of dry weight of material in a unit of time (t) (Guda et al., 2017). The drying rate was computed using Eq. 3. The fat content (FC) of cacao was investigated under the Soxhlet method. The samples (w1) were dried, ground into small particles, placed in the porous thimble, and weighed as w2. The flask was heated to evaporate the solvent and move to the condenser. Then, it was converted into a liquid and collected into the sample's extraction chamber. When the solvent passed through the sample, it extracted the fats, carried them into the flask, and weighed as w3. The fat content was calculated using Eq. 4. The hardness of cacao beans is measured using a hardness tester. The sample was put below the nozzle point, and the nozzle was stuck on the sample, and after several seconds, the measurement was displayed on the monitor.

\[
MC_{wb} = \frac{m_1 - m_2}{m_1} \times 100\% \\
MC_{db} = \frac{m_1 - m_2}{m_2} \times 100\% \\
R = \frac{dMC_{db}}{dt} \\
FC = \frac{w_3 - w_2}{w_1} \times 100\%
\]

Figure 2. The study used the open sun-drying cacao (a) and modified solar tunnel dryer type Hohenheim (b).

**Results**

**The drying temperature of cacao under modified solar tunnel dryer type Hohenheim**

The first important parameter in the drying process is the temperature. The growth of temperatures during 2 days of the drying process can be seen in Fig. 3. The total drying time was 12 hours. The average drying chamber temperature was 42°C, while the average sun-drying temperature was 30°C. Thus, the modified Hohenheim solar tunnel dryer increased the drying temperature by about 12°C. The maximum temperatures reached on the first- and second-day drying were 59 and 64°C, respectively. However, the temperature deviation inside the drying chamber was still much higher, about 11 to 13°C compared to the temperature deviation of sun-drying about 3 to 5°C.

**Drying humidity of cacao beans under modified solar tunnel dryer type Hohenheim**

The second important parameter in drying is relative humidity. On the first day, the average humidity in the drying chamber was equal to the sun-drying at 73%, while on the second day, the average humidity in the drying chamber (70%) was lower than that of sun-drying (76%). It showed that humidity in the drying chamber needs to be reduced so that the airflow in the chamber needs to be improved. The evidence of the lowest humidity at 11.00 am. on the first day can be caused by the higher temperature than average. For this reason, the following modification on the dryer could be conducted by increasing the number of fans and their capacity.
The drying process was controlled by weighing 100g samples every hour. At the end of the drying process, the final moisture of cacao was 12.7 and 17.4%, respectively. Based on the data of weight loss, the moisture of cacao during the drying process calculated by using Eq.1 can be seen in Fig.5. The chart showed that the drying by using a modified type Hohenheim solar tunnel dryer was faster than that of the sun-drying method. At the beginning of the drying process, the changes in sample weight in both drying methods were equal. Later, the drying rate of the modified type Hohenheim dryer increased sharply, so the drying process using this dryer was much faster than the sun-drying method. According to the Fig. 5, the total drying time was about 12h, namely 8h on the first day and 4h on the second day. The drying process was stopped because the moisture had reached 14% wb. The drying rate curves of both drying methods are shown in Fig.6.

**Figure 3.** The temperature during the cacao drying under 2 methods for 2 days of observation.

**Figure 4.** The humidity during the cacao drying under 2 methods for 2 days of observation.

The profile of moisture loss and drying rate

The drying process was controlled by weighing 100g samples every hour. At the end of the drying process, the final moisture of cacao was 12.7 and 17.4%, respectively. Based on the data of weight loss, the moisture of cacao during the drying process calculated by using Eq.1 can be seen in Fig.5. The chart showed that the drying by using a modified type Hohenheim solar tunnel dryer was faster than that of the sun-drying method. At the beginning of the drying process, the changes in sample weight in both drying methods were equal. Later, the drying rate of the modified type Hohenheim dryer increased sharply, so the drying process using this dryer was much faster than the sun-drying method. According to the Fig. 5, the total drying time was about 12h, namely 8h on the first day and 4h on the second day. The drying process was stopped because the moisture had reached 14% wb. The drying rate curves of both drying methods are shown in Fig.6.
Figure 5. The moisture-wet basis of cacao drying under 2 methods for 2 days of observation.

Figure 6. The drying rate of cacao drying under 2 methods for 2 days of observation.

The highest drying rate of cacao dried using a Hohenheim-type solar tunnel dryer was 24 %db/h, and it happened on the first day from 11.00 to 12.00 am. The drying temperature and relative humidity in the drying chamber were 52°C and 39%, respectively. Another incident of higher drying rate was obtained from 2.00 to 3.00 pm at 20 %db/h, where the temperature had reached 55°C. It was indicated that the best drying rate for cacao could be produced at a drying temperature of around 50 to 55°C. Under the sun-drying method, the highest drying rate of cacao was 12 %db/h. It can be said that the drying rate of cacao under a type of solar tunnel dryer was double that of the sun-drying method.

The quality of cacao beans

The quality of cacao was observed based on moisture content, fat content, and hardness of the bean. The data are shown in Table 1. After 12 hours of intermittent drying in 2 days, the moisture of cacao dried using a modified type Hohenheim solar tunnel dryer was lower than that of the sun-drying method. This condition caused the higher fat content of cacao to be dried using a Hohenheim dryer. However, since the average drying temperature did not exceed 55°C, the fat content of cacao dried by both methods was good. At the same time, the hardness of cacao increased as the moisture decreased.
According to the Indonesian National Standard for cacao (SNI 7934:2014), the minimum fat content for black cacao was 18% (BSNI, 2014). Therefore, the fat content of cacao dried in both methods had met the standard. Moreover, it was assured that the quality of cacao dried using a solar tunnel dryer was much better since the plastic sheet cover fully protected the cacao from contamination, such as dust, dirt, and so on.

<table>
<thead>
<tr>
<th>Quality properties of cacao</th>
<th>Drying methods</th>
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<tbody>
<tr>
<td></td>
<td>Hohenheim solar tunnel dryer</td>
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<tr>
<td>Moisture (%wb)</td>
<td>12.7</td>
</tr>
<tr>
<td>Fat content (%)</td>
<td>36.7</td>
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<tr>
<td>Hardness (kg/cm²)</td>
<td>3.273</td>
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</table>

Discussion

The increased temperature in the drying chamber of solar tunnel dryer type Hohenheim was confirmed by a previous study on drying chili, where the average temperature of the drying chamber had been increased significantly from the ambient temperature, from 10 to 20°C (Ridwan et al., 2017). Khathir et al. (2020) also observed the temperature difference between the drying chamber and the environment, which was about 16.85°C. Under a smaller design, the drying chamber temperature was increased to 8.14°C from the ambient temperature (Khathir et al., 2021). Overall, it can be said that the design of the modified tunnel dryer type Hohenheim ran properly in increasing the drying temperature.

It has also been reported that the Hohenheim-type solar tunnel dryer could produce temperatures up to 80°C (Green and Schwarz, 2001). Nevertheless, the optimal temperatures for drying cacao were indicated to be 60°C (Hayati et al., 2012) and 55°C (Dina et al., 2013). According to Deus et al. (2018), the drying process using the sun-drying method at temperatures below 60°C resulted in the optimum quality of cacao by showing the best retention of antioxidant activity. Therefore, it is very important to control the temperature in drying cacao so that it does not exceed 55°C. In the case of this design of a modified solar tunnel dryer type Hohenheim, the manual control of temperature can be done by opening the cover sheet for a few minutes. The subsequent modification of the dryer is needed to control the temperature below this point, probably by introducing the outlet fans.

Another finding is that the temperature deviation inside the drying chamber was higher than sun-drying. This condition was reflected by the fluctuation of solar irradiation. It was reported that an increase of 100 W/m² of solar irradiation would lead to the increase of temperature inside the modified type Hohenheim solar tunnel dryer by about 2.19°C, where the r-square of this model was 61% (Khathir et al., 2021).

Although the dryer design could improve the drying temperature by collecting the solar irradiation, there is no apparatus to store the heat in this design. Therefore, it is important to continue modifying the dryer by installing a heat storage system to improve the temperature stability in the drying chamber. The use of desiccant thermal storage, i.e., molecular sieve 13x (Na86 [(AlO2)86. (SiO2)106]. 264 H2O) dan CaCl2 made the drying more effective in terms of shorter the drying time of cacao at 41 and 30h, respectively (Dina et al., 2015). To achieve the best product quality, the drying temperature must be stable at a certain level that does not exceed the optimal temperature for each product to be dried. Therefore, a temperature controller is also necessary for this dryer.

Theoretically, increasing the temperature by about 1°C should decrease the humidity by 4% (Taib et al., 1988). Since this type of dryer uses air as the medium for the drying process, the humidity of the drying chamber is highly influenced by the humidity of the environment. The local climate influenced the high humidity under the sun-drying method. In contrast, the high humidity inside the drying chamber was caused by the high moisture of cacao at the beginning of the drying process, fluctuation of solar irradiation reflected by lower temperature, and low airflow. Furthermore, the exact condition was described when drying cacao using an intermittent solar dryer backed up by a heat storage chamber filled with gravel, especially at night, when the humidity has reached...
about 98% (Fagunwa et al., 2009). Running the drying process in the absence of solar irradiation or during the night period will lead to the need for higher energy to reduce the air humidity before entering the dryer.

The initial moisture of cacao was 59%. Several studies have reported the variation in the initial moisture of cacao, for example, at 56.6% (Chinenye et al., 2010), at 54.34% (Hayati et al., 2012), at 52.18% (Deus et al., 2018), and about 49.86% (Guda et al., 2017). The growing condition and the variety itself can cause variations in the initial moisture of cacao.

The total drying time needed to reduce the moisture of cacao beans at 14% was 12h. In comparison to this result, the open yard sun drying was reported to reduce the cacao moisture from 49.86 to 7.14% in 30h, the microwave oven could reduce the cacao moisture from 49.43 to 7.59% in 10min, the use of a solar cabinet dryer could reduce the cacao moisture from 49.88 to 6.36% in 16h, and the use of tray dryer could reduce the cacao moisture from 49.35 to 7.45% in 7h (Guda et al., 2017). Another study reported that the total drying time for cacao under the sun-drying method was 55 hours (Dina et al., 2015). So, using a modified solar tunnel dryer type, Hohenheim performed similarly to the solar cabinet dryer, and there is a big opportunity to reduce drying time to improve the quality of cacao by using a solar dryer.

As shown in Fig.6, the drying rate of the modified solar tunnel dryer type Hohenheim was higher than that of the sun-drying method. However, since the temperature in the drying chamber depended strongly on the availability of solar irradiation, the temperature fluctuation still cannot be avoided. The development of a heat storage system in the next modification should be studied to solve this problem. In addition to this, the improvement of the air circulation system is also important. Last but not least, the drying of cacao beans using a solar tunnel dryer type Hohenheim can protect the products from contamination during the process. It will affect the quality of cacao beans to be better in the future.

Conclusion

The modified solar tunnel dryer type Hohenheim is promising to be used for drying cacao because it can speed up the drying time compared to the sun-drying method. The average temperature in the drying chamber (42°C) was higher than that of sun-drying (30°C), while the average humidity in both conditions was high (above 70%). Although the dryer worked properly in drying cacao, it needs further modification to improve air circulation by increasing the number and capacity of inlet fans and introducing outlet fans. Furthermore, heat storage and biomass stove modification can be applied to optimize the dryer performance.

Acknowledgment

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References

BSNI, 2014. SNI 7934: Cokelat dan produk produk cokelat. BSNI.