Drying Profile of Coarse Coconut Palm Sap Sugar Using Simple Air-Oven Dryer

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ABSTRACT
The influence of different drying temperatures and drying loads on the drying characteristics of coarse coconut palm sap sugar were investigated in this study. The granulated coconut palm sap sugars were dried using an air-oven dryer at three temperature variations (60, 70, 80ºC) and three different drying loads of 5, 10, and 15 kg. The drying profile of the coarse coconut palm sap sugar was determined by monitoring moisture loss over the drying period. The result showed that the moisture removal rate increased with the drying temperature. However, increasing the drying load from 10 to 15 kg did not significantly affect the drying rate at all temperature variations, resulting in the highest drying efficiency achieved at the highest drying temperature of 15 kg. Furthermore, the predicted moisture content calculated using the obtained drying rate constant value showed a high correlation with the reference value denoted by the R^2 over 0.95 for all experimental conditions. The results have demonstrated that different drying approaches may affect the drying period of coconut palm sugar using a simple air-oven dryer.

Keywords: *drying rate, temperature, dryer load, drying efficiency, coarse coconut palm sugar.*

1. INTRODUCTION

Various types of sugar can be derived from different sources of raw material, including sap collected from palm trees which commonly grow in tropical countries. The sap can be tapped from the flower of *Arenga pinnata* Merr and *Cocos nucifera* trees in Indonesia and Malaysia [1]–[3], *Borassus flabellifer* tree in Thailand [4], and date palm in other countries [5]. Palm sugar, known as jaggery in India, and brown sugar in Indonesia and Thailand, were mainly used as a sweetener for beverages and foods. However, it is also utilized to improve various traditional foods' color, aroma, and taste [6].

In the market, palm sap sugar can be found as syrup, molded sugar, or granulated (coarse) sugar, which is closely related to the production process. The syrup type is produced by boiling the sap until it reaches a particular Brix value. The procedure to produce a molded type of sugar is similar to the syrup type. However, the boiling process continued until the highly viscous sap sugar is obtained and then molded using a coconut shell or bamboo mold to form a solid sugar [7], [8]. Then, the further heating process of highly viscous sap sugar into supersaturated condition is carried out to produce the third type of palm sap sugar (granulated or coarse).

To generate sugar crystal, the supersaturated sap is cooled while continuously stirred. The obtained crystals are then subjected to the grinding process to produce a uniform size of sugar powder. However, the sugar powder usually still contains 8% water which is higher than the value of maximum moisture content for commercial sugar. Hence, the drying process is needed to evaporate moisture left in the sugar [9] to extend its shelf life [10]. Therefore, drying is crucial in producing powdered palm sugar [11].

In Indonesia, palm sap sugar is generally produced by a small home industry with limited facilities. Therefore, direct sun drying has been commonly applied to remove the remaining water in sugar. However, despite its cheapness, this drying method has several drawbacks, such as unpredictable drying times, requiring large areas, and a high probability of physical and biological contamination from the environment [12]. Hence, introducing a simple drying machine is necessary to overcome the above-mentioned disadvantages of direct sun drying.

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A simple and low-cost air-oven dryer is a wise choice to replace the usage of direct sun drying for granulated palm sap sugar. This dryer can reduce up to 3% water content of *Arenga pinnata* sugar in 60 minutes. In total, about 3.3 hours were needed to dry 30 kg of sugar and reduce water content from 5 to 2,6% [12]. However, this research did not present the drying profile of the sugar. Therefore, investigation of the drying profile by monitoring moisture loss over drying period can be used to predict drying time.

On the other hand, drying rate is affected by the capability of air to carry water that evaporated from the product. Hence, drying load and temperature will affect the drying rate. Moreover, every dryer has its own characteristics. Thus, this research aims to investigate the drying profile of coarse coconut palm sap sugar to determine the most effective condition using a simple air-oven dryer.

2. MATERIAL AND METHOD

2.1. Material

The coconut palm sugar used in this experiment was obtained from a small industry located in Kulonprogo District, Yogyakarta, Indonesia. All experiments were assessed under a complete factorial design with two factors of drying temperature (60, 70, and 80ºC) and drying Load (5, 10, and 15 kg) to clarify the drying kinetics. During the drying process, the coarse coconut palm sap sugar was spread on the shelve with a maximum capacity of 2.5 kg each to obtain a maximum thickness of 1 cm. Therefore, in this experiment, we used 2, 4, and 6 shelves for 5, 10, and 15 kg drying loads, respectively. Moreover, the investigation was conducted with three repetitions for each treatment; thus, in total, we used 90 kg of sugar.

2.2. Experimental setup

The air-oven dryer used in this research was locally manufactured and had dimensions of 120 cm in width, 170 cm in height, and 50 cm in depth. This dryer was also equipped with a Liquid petroleum gas (LPG) stove as an energy source for heating air used for the drying process. An automatic control was added to maintain the stove based on the temperature measured in the drying chamber. An axial blower was used to circulate air inside the dryer cabinet which was divided into two parts, and each part had five shelves. This air-oven dryer also had an air outlet on top of the cabinet. The schematic diagram and the inside photograph of the dryer can be seen in Figure 1.

During the drying process, the temperature of the sample at every shelve was monitored using a digital temperature. The amount of water removal was also evaluated periodically every 10 minutes by measuring the sample weight. After finishing the drying process, the moisture content of the sample was measured using thermogravimetric method. The sample's moisture content in each time interval during the process was then calculated based on the sample weight and presented on a dry basis.

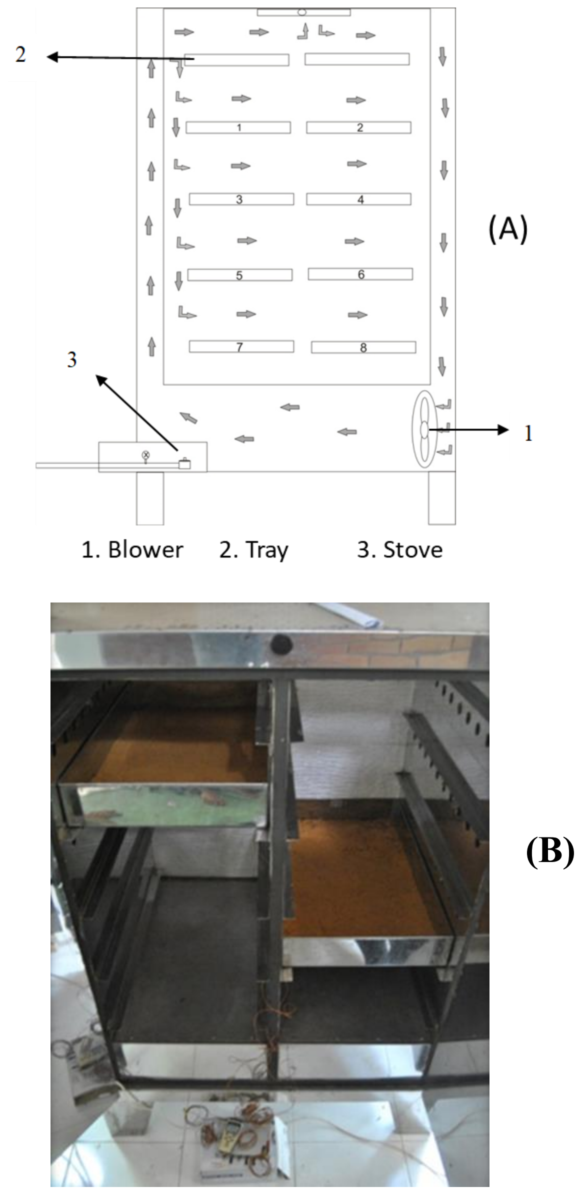

Figure 1 Schematic diagram (A) and the inside photograph (B) of the air-oven-dryer

2.3. Data Analysis

The moisture content of the sample was normalized using a moisture ratio (MR) and expressed as Equation 1

$$MR = \frac{M_t - M_e}{M_i - M_e} \quad (1)$$

where M denotes moisture content and subscripts i, t, and e represent initial drying time, a certain time, and equilibrium, respectively. The value of the moisture content in this experiment was expressed in dry basis (%db). The obtained MR from 27 experimental runs with three various drying temperatures, three drying loads, and three repetitions of each variation were fitted to an empirical Page equation, shown in Equation 2:

$$MR = \exp(-kt^n) \quad (2)$$

where k represents the drying rate constant, and n is power constant. The n value was equal to 1 due to the drying process occurred in the falling rate period.

The obtained k values of each treatment were then averaged and used to predict the moisture content of the sample, using Equation 3:

$$M_t = M_e + (M_i - M_e)\exp(-kt) \quad (3)$$

This research also evaluated drying efficiency, used to select the best operating conditions of the manufactured dryer. The calculation of the drying efficiency was expressed as Equation 4:

$$\eta = \frac{(m_s \times C_{ps} \times (T_s - T_{si}) + (m_u \times H_w)}{m_g \times L} \times 100\% \quad (4)$$

where m_s, m_u, and m_g represent the weight of the sample, water removal, and LPG used, respectively. T_s denotes the highest sample temperature during the drying process, while T_{si} represents the initial temperature of the sample. The C_{ps} symbol refers to the specific heat of the sample (1.19 kj kg^{-1} K^{-1}) [13], H_w represents latent heat evaporation of water, and L expresses the heat combustion of LPG.

2.4. Statistical analysis

Statistical analysis was performed using SPSS software. The values of drying rate (k) and drying efficiency were subjected to the variance analysis.

3. RESULT AND DISCUSSION

3.1. Moisture content of coarse palm sap sugar during drying process

The profile of the sample moisture contents during the drying process is presented in Figure 2. The moisture equilibrium of 80°C drying process could reach below 3%, while the other two drying temperatures of 60 and 70 were above 3% for all various drying loads. Moreover, Figure 2 also showed that increasing drying temperatures speed up the sample to reach its moisture equilibrium. A similar result was presented by Chupawa et al. [14] when dried red Jasmine rice using a fluidized-bed-dryer. Higher air temperature supplies more energy that can be used to evaporate water. Increasing temperature also decreases water pressure in the air, leading to a higher capability to carry water from the sample.

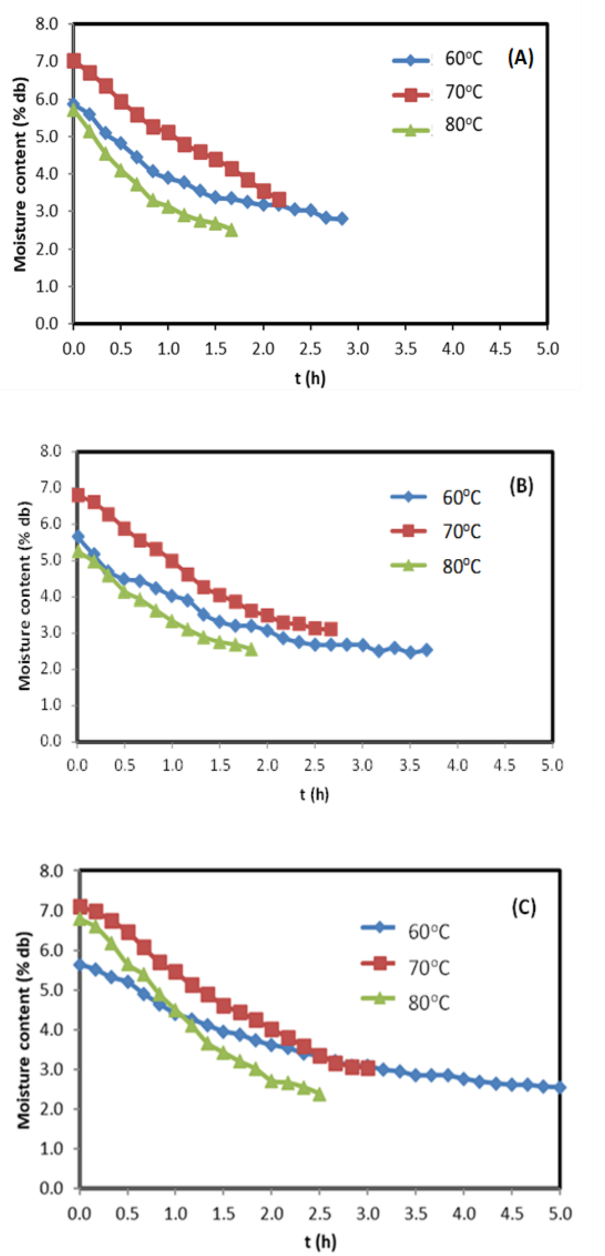

Figure 2 Moisture content profile during drying process at various temperatures for 5 kg (A), 10 kg (B), and 15 kg (C) of drying Load

3.2. Drying rate constant

Page equation was a common equation used to evaluate drying rate of agricultural and food samples. For example, this equation was used to assess drying rate of red pepper [15] and banana [16]. In this research, a Page equation with a constant exponential value (n = 1) was used to evaluate the dying rate of the coarse coconut palm sap sugar at the falling rate period. The result of the analysis is presented in Table 1.

Table 1. Drying rate constant value at various drying temperatures and drying rate

Drying Load (kg)	Drying rate values (k) at various Drying temperatures (h^{-1})		
	60^oC	70^oC	80^oC
5	$0.31^{a,1}$	$0.34^{b,1}$	$0.56^{c,1}$
10	$0.27^{a,2}$	$0.32^{b,2}$	$0.43^{c,2}$
15	$0.19^{a,3}$	$0.29^{b,2}$	$0.44^{c,2}$

Different subscript "letters" at the same row indicate significantly different
Different subscript "number" at the same column indicate significantly different

Table 1 shows that the value of drying rate (k) increases following the increasing temperature. This condition indicates faster water removal. In addition, increasing the temperature of air drying will lower water pressure on the air, meaning increasing the capability to carry moisture of the sample. Meanwhile, the change of the drying load from 10 to 15 kg did not affect the drying load, especially at 80^{o}C drying temperature. This condition means that the highest drying efficiency will be reached at the highest drying temperature and drying Load (80^{o}C and 15 kg), as presented in Table 2.

Table 2. Drying efficiency at various drying temperatures and drying loads

Drying load (Kg)	DryingTemperature (^{o}C)	Drying efficiency (%)
5	60	2.64^a
	70	3.05^b
	80	4.00^c
10	60	2.74^a
	70	4.68^d
	80	5.72^e
15	60	3.09^b
	70	7.88^f
	80	8.49^g

4. CONCLUSION

The rate of moisture removal from coarse coconut palm sap sugar increased following the increase of drying temperatures from 60 to 80^{o}C. However, increasing the drying load from 10 to 15 kg did not affect the drying rate significantly. Therefore, the optimum drying approach for the specified dryer used in this experiment was at 80^{o}C for a 15 kg drying load.

AUTHORS' CONTRIBUTION

The author's contribution to the paper is as follows: data curation: Erlinda Tiarasari, Rizayu Wulandari; Writing original draft: Erlinda Tiarasari; Data analysis: Erlinda Tiarasari, Hanim Z. Amanah; Conceptualization: Sri Rahayoe, Hanim Z. Amanah; Writing review and correction: Hanim Z. Amanah

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