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Improving the Moisture Quality of Crystalline Coconut Palm Sugar through Post-Oven Heating in a Small-Scale Industry

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Abstract. Crystalline coconut palm sugar has greater market potential than molded brown palm coconut sugar, but products from small-scale processors often exhibit inconsistent moisture content. This study evaluated the effect of post-oven heating on the yield and moisture content of crystalline coconut palm sugar produced from the coconut palm tree (*Cocos nucifera* L.) in Malang Regency, Indonesia. The crystalline coconut palm sugar used in this study was produced from molded coconut palm brown sugar, which was then crushed into samples, with up to 25 units per treatment. The oven temperature was set to 60 0C with a heating time of 1 hour. While measuring the moisture content of crystalline coconut palm sugar based on the Gravimetric method, the treatment reduced the moisture content from (14.60 + 2.20) % before oven heating to (10.44+1.08) % after oven heating, while yield decreased from (336.56 + 8.52) g to (323.44 + 7.27) g per 2 L of sap ($p < 0.05$). These findings indicate that post-oven heating can improve moisture quality, although further evaluation of shelf-life, sensory properties, and cost-effectiveness is required before scale-up.

1 Introduction

Coconut palm tree (*Cocos nucifera* L.) sugar is derived from the sap or nectar of the coconut palm tree. It has been a traditional sweetener in Asia for thousands of years. Currently, traditional processing of coconut palm sap results in lower yields and higher costs. There is significant potential to develop processing techniques (traditional processing, spray drying, membrane technology, and vacuum drying) to optimize coconut palm sugar production [1]. Coconut palm sugar has a higher reducing sugar

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content than refined cane sugar or industrially produced sugar. It has been reported that intense heating of palm coconut sugar, especially at high temperatures and for long heating times, can accelerate the hydrolysis of sucrose, producing reducing sugars. However, the high reducing sugar content in the sugar will also affect its brown color after the Maillard reaction [2].

Traditionally, coconut palm sugar is shaped into circles of various sizes, tubes, and cubes, and it complements kitchens and traditional dishes. To meet culinary and industrial needs, innovation in the size and shape of coconut palm sugar products is necessary, and these changes must be integrated into manufacturing processes. A common processed form of coconut palm sugar is crystalline sugar, though MSMEs typically produce it with higher water content and an inconsistent grain structure. Despite this, crystalline coconut sugar holds high sales potential both domestically and internationally. The advantage of crystalline coconut palm sugar is that it dissolves easily in hot or cold water and, with a lower moisture content, can be stored for up to a year without preservatives. It is available in different grades, including 10-13, 16, and 24 mesh [3].

The palm sugar market is projected to reach USD 1.78 billion in 2025 and USD 2.56 billion by 2030, reflecting a CAGR (Compound Annual Growth Rate) of 3.67% over the forecast period. Rising health awareness, demand for low-glycemic foods, and clean-label claims are driving palm sugar from a niche health sweetener to broader acceptance used as an ingredient in household cooking and traditional foods. Government programs in Indonesia, the Philippines, and Vietnam are improving farmers' productivity and product standardization, ensuring a reliable regional supply. Premium positioning allows prices 300-400% higher than refined cane sugar, while new processing technologies, such as vacuum dehydration, preserve flavor and extend shelf life, encouraging wider distribution [4]. The palm sugar market is dominated by regional and local players, who hold around 70-75% of the market share. Unlike local players, multinational companies hold a very low market share (5-10%) due to the high price of palm sugar. Indonesia is the largest producer of palm sugar [5]. The sales value of crystal sugar will increase by up to 400% compared to that of coconut palm sugar bars [6].

This study aims to enhance the quality of crystalline coconut palm sugar by applying a heating process. Local coconut palm sap-tapping methods were employed during the production process to create value-added opportunities for local farmers. Therefore, by processing coconut palm sugar into crystalline coconut sugar, consumers will be more attracted to granulated crystalline sugar over coconut palm sugar bars, especially at home or in coffee shops, hotels, hospitals, modern retail outlets, and modern markets. In addition to its better quality, its attractive packaging design will also increase its sales value. Prior to the coconut palm sugar farmer, a study of the processes for producing coconut palm crystalline sugar was conducted. The purpose of this study is to improve the quality of crystalline coconut palm sugar products by using a temperature-treatment approach to reduce moisture content, thereby increasing the selling value of coconut palm sugar produced by small-scale industries in Malang Regency.

2 Materials and methods

2.1 Materials

Fresh coconut palm sap was obtained from coconut palm trees (*Cocos nucifera* L.) with a plant age of about 10-15 years, cultivated in Bantur district, Malang regency, East Java province, Indonesia. Sap was collected from 3 experienced local farmers, each providing 5 independent batches, for a total of 50 experimental samples (50 L of sap). Each sample was considered a single biological replicate. Fresh sap from the coconut palm tree was harvested between 6:00 and 7:00 AM (morning collection) after overnight collection, using clean, food-safe bamboo or plastic containers. The collected coconut palm sap was heated and boiled to evaporate water. The coconut palm sap was concentrated in a stainless-steel pan using continuous heating at 95–100°C with constant stirring until the dissolved solids reached approximately 95–97°Brix. Additional materials used to process coconut palm sap into mold coconut palm sugar included firewood and LPG. Mold coconut palm sugar production is also carried out in the Bantur district.

2.2 Methods

A comparative study was conducted to evaluate the non-heating treatment versus heating processes for crystalline coconut palm sugar. The variables observed in this study were crystalline coconut sugar, both unheated and oven-heated. The crystalline coconut sugar was at room temperature (27-30 °C) before heating, and the oven was heated to 60 °C for 1 hour. To reduce the size of coconut sugar and obtain crystalline coconut sugar grains, a wooden pestle hand crusher, 6 cm in diameter and 15 cm in length, was used to crush molded coconut sugar. To obtain a 20-mesh powder, a 20-mesh aluminum sieve was used to screen the coconut sugar before packaging, ensuring a uniform, crystalline product.

2.3 Data collection and statistical analysis

Data were analyzed using the dependent-samples t-test, which is a statistical test used to determine whether the mean difference between two related samples is zero. In this test, each object or entity is measured twice, resulting in two sets of observations. The sample t-test is widely used in case-control studies and in designs that require repeated measurements [7]. In this study, the aim was to determine the effectiveness of producing crystalline coconut sugar with and without oven heating. Using the paired-samples t-test, the difference between crystalline coconut sugar products before and after oven heating can be examined and its significance assessed. Statistical analysis was performed using Excel's Data Analysis ToolPak, the primary statistical tool. A significance level of $P<0.05$ was used to assess the variables.

3 Results and discussion

3.1 Coconut palm sugar production

Coconut palm sugar is typically produced by evaporating coconut palm sap in an open pan until a thick paste forms. This sugar is not refined or produced using synthetic chemicals, which may confer nutritional benefits [8]. The raw material for coconut sugar is the sap from the flower stalks of coconut palm trees. Figure 1 illustrates the production stages of molded coconut sugar. Fresh sap is highly perishable and must be cooked immediately after tapping to prevent fermentation and quality degradation [9]. If fermentation occurs, the sap can become cloudy, yellowish, and sour, and the resulting sugar may fail to crystallize properly [10]. The molded coconut sugar is used to produce crystalline coconut sugar. Crystalline coconut sugar has become an increasingly common practice in the sugar industry to meet growing market demand for high-quality products. The final product of crystalline coconut sugar has lower water content, a smoother texture, better cleanliness, and a longer shelf life [11] [12].

(A) **(B)**

Fig. 1. Traditional coconut palm sugar making from coconut palm sap: A) Cooking by evaporating coconut palm sap in a pan over firewood is used as cooking fuel, and B) Pouring cooked coconut sap into a bamboo mold to produce molded coconut palm sugar

Cooking coconut palm sap to make coconut palm sugar is done after the sap is filtered. The sap is then poured into a large pan or a special container for cooking sugar and heated over firewood to 120-130 °C (**Fig. 1**), or heated using the open-heat evaporation (OHE) technique. Coconut palm sugar has a caramel color and a brown-sugar-like flavor. It is commonly used as a natural sweetener. However, coconut palm sugar produced from coconut palm sap uses traditional methods that involve heating the sap at high temperatures (>100°C) in an open pan for extended periods (3–5 hours). This conventional method produces overcooked sugar, which leads to a decline in both its physical and chemical properties [13]. The capacity or mass of the cooked material affects the rate of temperature change. If the capacity is small, the rate of temperature change will be faster. This is because the water contained in the material evaporates quickly [14]. The constant change in temperature (kT) during the evaporation process can be influenced by mass: the more material processed, the slower the heat transfer, so kT will also be smaller [15]. The yield of coconut palm molded sugar from coconut palm tree sap was an average of 336.56 + 8.52 g, as presented in **Table 1**. Asghar's [13] study reported that 1 L of fresh coconut sap (approx. 1,000 grams) yields roughly 124 to 135 grams of total solids/sugar.

Table 1. The yield of coconut palm molded sugar from the sap of the coconut palm tree

Sampel (n)	Average coconut palm sap volume (L)	Average yield of molded coconut palm sugar (g)
25	2	336.56 $\pm$ 8.52

In the traditional method of coconut palm sugar production, processing is usually carried out using a large pan/container, into which filtered coconut palm tree sap is poured. The sap is heated and cooked by manual stirring and shaking for approximately 3–4 hours until the water evaporates, resulting in a very thick, sticky texture. This texture indicates a high concentration of coconut palm sugar (approximately 93 g per 100 g). The sugar is brown in color due to the Maillard reaction [16]. The sugar is poured into a coconut shell, a wooden, or a bamboo mold. The sugar cools and hardens within 1 hour [17]. Disadvantages of this method include an undesirable color (dark brown). In addition, the antioxidant properties and phenolic content of palm sugar are reduced due to prolonged heating. Because an open-pan evaporator is used, a greater sucrose inversion is observed. Furthermore, hydroxymethyl furfural is formed. The resulting sugar has a slightly bitter taste [17] [18].

3.2 Coconut palm sugar production

To diversify product offerings and improve the quality of coconut palm sugar derived from sap, crystalline coconut palm sugar has been developed. Crystalline coconut palm sugar is a modification of coconut palm sugar with a higher degree of dryness, resulting in a longer shelf life compared to molded coconut palm sugar in general. Crystalline coconut palm sugar can be produced directly from fresh sap or by melting and recrystallizing it. Compared with conventional coconut palm sugar production, this method requires longer processing times due to additional steps, such as drying and sieving, to achieve a uniform particle size [19] [20]. The product of crystalline coconut palm sugar in this study is shown in **Fig. 2.**

(A)

(B) **(C)**

Fig. 2. Crystalline coconut palm sugar production: A) Hand-grinding and sieving the molded coconut palm sugar to produce crystalline coconut sugar, B) Crystalline coconut sugar product, and C) Packaging of crystalline coconut palm sugar product

Table 2 shows the crystalline coconut palm sugar product with and without oven heating. The coconut palm tree sap yielded an average of 336.56 + 8.52 g of crystalline coconut palm sugar (without oven heating) and 323.44 + 7.27 g (with oven heating). The temperature before oven heating is room temperature (around 27-30 °C), and the oven-heated temperature is around 60 °C for one hour of heating.

Table 2. Crystalline coconut palm sugar yield with and without oven heating

Sample (n)	Average Palm Sap Volume (L)	Average Crystalline Coconut Palm Sugar Yield (g)	
		Without Oven Heating	With Oven Heating
25	2	336,56 ± 8.52	323,44 ± 7.27

Note: Significant difference between without oven heating and with oven heating at $p < 0.05$ based on paired t-test

Heating temperature significantly influences the quality of crystalline coconut sugar by controlling water evaporation, supersaturation, and sucrose crystallization. Higher temperatures facilitate moisture removal, leading to higher concentrations of soluble solids until supersaturation occurs, which encourages crystal nucleation and growth. Proper thermal processing yields crystalline sugar with reduced moisture content, improved flowability, and enhanced storage stability [21]. Regarding Arenga palm sap crystallization, the influence of key parameters on the process has been demonstrated, including temperature, pH, and heating technique [22]. Most sugars, particularly non-reducing sugars, can be crystallized. However, because anomers and ring isomers are present in solution, making reducing sugars intrinsically "impure," it can be challenging to obtain some reducing sugars in crystalline form. Therefore, the presence of reducing sugars can prevent the crystallization of non-reducing sugars.

Paired t-tests demonstrated a significant difference in moisture content, from an average of 10.60 + 2.20% without oven heating to 6.44% + 1.08% with oven heating ($P<0.05$) (**Table 3**). The findings suggest that oven heating improves sugar quality by reducing moisture content. The lower moisture content observed with oven heating favors the quality of the crystalline coconut sugar. Humidity is an important factor affecting water activity (aw), flowability, and shelf life of powdered sugar. As humidity decreases, water activity also decreases, reducing microbial growth and slowing physicochemical deterioration during storage [22].

Table 3. Moisture content of crystalline coconut palm sugar without and with oven heating

Sample (n)	Average Moisture Content (%)	
	Without Oven Heating	With Oven Heating
25	14.60 $\pm$ 2.20	10.44 $\pm$ 1.08

Note: Significant difference between without oven heating and with oven heating at $p < 0.05$ based on paired t-test

Moisture content is another key factor in determining palm sugar quality. Products from small-scale producers often have high moisture content, ranging from 6% to 7%, exceeding the maximum limit set by the Indonesian National Standard (SNI) [23] [24]. High moisture content produces coarser crystals and a moister texture, shortening shelf life and increasing the risk of caking during storage [17]. Moisture content is influenced by several factors, including the cooking endpoint. If cooking stops too early, insufficient water evaporation results in a higher moisture content in the final product [24]. Adding ingredients during processing can also introduce impurities that increase the product's hygroscopicity, increasing its tendency to absorb moisture from the environment. The drying process is another important factor in determining the final moisture content.

Reducing the moisture content of crystalline coconut sugar is crucial for improving storage stability and minimizing caking. Traditional solar drying is still widely practiced due to its simplicity and low operational costs. However, this process is highly dependent on climatic conditions and exposes the product to airborne contaminants, insects, and microorganisms, potentially compromising food safety and quality [25]. To address this, mechanical drying equipment has been introduced to improve product quality and processing efficiency. Mechanical drying technologies have become an attractive alternative. Air oven dryers, tray dryers, and rotary dryers operate under controlled temperature and airflow conditions, enabling simultaneous heat and mass transfer, thereby enhancing moisture removal while maintaining more consistent product quality. Studies in coconut sugar production have shown that drying temperature significantly affects drying kinetics, and mathematical models can accurately predict moisture reduction under controlled drying conditions. Wulandari et al. [15] and Kurniawan et al. [23] reported that a cylindrical rack dryer reduced moisture content from 5.40% to 3.02% in 3 hours at 60°C. Zuliana et al. [26] also reported moisture content ranging from 1.37% to 2.43% in mechanically dried palm sugar, which was lower than that obtained through traditional processes. Meldayanoor [27] reported that oven drying at 100°C for 1 hour yielded palm sugar with a water content of 2.97%, which is considered optimal for consumer preferences.

4 Conclusion

This study highlights the potential to improve the quality of crystalline coconut sugar by applying oven heating in small-scale industries. Hopefully, crystallized coconut sugar could enhance the product's marketability, provide additional income for farmers, and align with international quality standards. The study showed that oven heating could reduce the moisture content in crystalline coconut sugar. Hence, this technique can be used in small-scale industries to improve the quality of crystalline coconut sugar by reducing its moisture content. In Indonesia and other countries, coconut sugar production and processing remain local and small-scale. Thus, future studies may explore scalability and cost-effectiveness for broader industry applications. Furthermore, more advanced technologies need to be developed to enable large-scale coconut sugar production that meets national and international market standards. Given the coconut palm tree's significant potential in Indonesia, the production of crystalline coconut sugar could become a major market worldwide.

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