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Influence of Evaporation Temperature on Palm Sugar Production via Atmospheric Evaporation Methods

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Abstract. Palm sap (Arenga pinnata) represents an important raw material for Indonesia's agro-industrial sector, particularly for palm sugar production. However, conventional processing often relies on refined sugar and additives, resulting in inconsistent product quality. This study investigates direct palm-sap crystallization under atmospheric evaporation to evaluate the influence of temperature (80, 90, 100, 110, and 120 °C) on product yield and physicochemical properties. The results show that increasing temperature enhances yield, reaching 16.11% at 120 °C, while moisture content decreases to 3.57%. Higher temperatures also lead to darker coloration and harder crystal texture. Ash content remains stable at approximately 1.5%. Reducing sugar levels increase with temperature, peaking at 13.91% at 110 °C, whereas sucrose content decreases significantly, with a minimum of 56.48% at 110 °C. Crystal size shows slight growth (1.28–1.33 mm), remaining within the SNI 3743:2021 limit. Overall, thermal conditions strongly influence sucrose inversion, sugar degradation pathways, and crystal formation behavior, highlighting the importance of temperature control in producing high-quality palm sugar.

1 Introduction

One type of sugar that is becoming increasingly popular is palm sugar, which has advantages in terms of taste, aroma, and its convenient form and packaging [1]. Palm sugar is made from palm sap (Arenga pinnata), a sweet liquid obtained from tapping the male flowers of the palm tree. Palm sap has a sweet taste, a distinctive aroma, and a high sugar content, making it a potential raw material for palm sugar production. Arenga pinnata (Wurmb) Merr. commonly known as the sugar palm, is a valuable commodity that supports the livelihoods of local farmers by providing a diverse array of products [2].

The main purpose of sugar production is the separation of sucrose from non-sucrose components followed by the crystallization obtaining sugar crystals of desired quality, e.g., purity, size distribution and color [3]. Crystallization is the process of separating dissolved substances from a solution through cooling, evaporation, or the addition of a crystallization

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agent (seeding), resulting in the formation of a solid crystal structure [4]. Generally, crystallization is divided into two types: cooling crystallization and evaporation crystallization. Cooling crystallization is performed by lowering the temperature of the saturated solution to form crystals. In contrast, evaporation crystallization is performed by removing the solvent (water) until the solution becomes saturated and crystals begin to form [5].

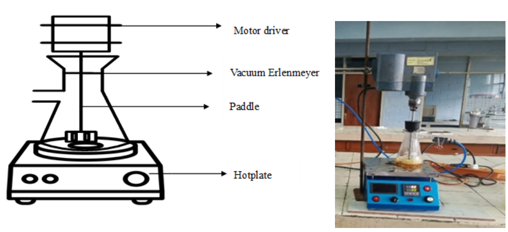
This study was conducted to determine the effect of evaporation temperature on the production of palm sugar through the process of atmospheric evaporation crystallization and cooling on quantity (% yield) and quality (% moisture content, % ash content, % preduksi sugar, and % sucrose sugar).

2 Research Methodology

2.1 Experimental Approach

The process of making palm sugar from palm sap is carried out through atmospheric evaporation, crystallization and cooling. The atmospheric evaporation crystallization cooling processes are carried out at evaporation temperatures of 80, 90, 100, 110 and 120°C.

2.2 Research Equipment



(a) (b)

Figure. 1 (a) Atmospheric Evaporation, Crystallization and Cooling Schematic (b) Photo of Atmospheric Evaporation, Crystallization and Cooling Equipment

2.3 Research Procedures

This is the research procedure that was implemented:

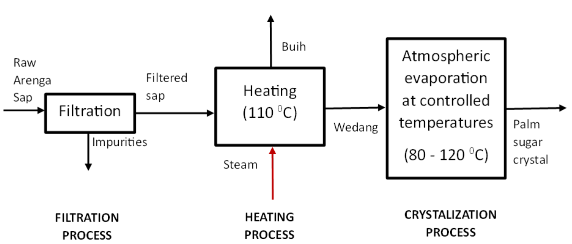


Figure. 2 Research Procedures (a) Preliminary Procedures (b) Palm Sugar Cooking Procedures (c) Atmospheric Evaporation, Crystallization Process and Cooling Process

2.4 Analysis

In the production of palm sugar through atmospheric evaporation, crystallization and cooling, it is necessary to analyze the moisture content, ash content, reducing sugar, and sucrose sugar. Moisture content and ash content are analyzed using the gravimetric method, while reducing sugar and sucrose sugar are analyzed using the Luff Schroll method.

3 Results and Conclusion

3.1 The Effect of Evaporation Temperature on the %Yield of Palm Sugar

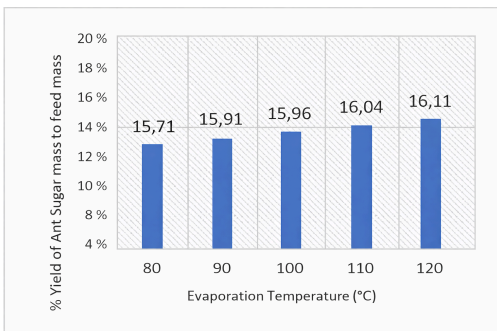


Figure. 3 The Effect of Evaporation Temperature on *%Yield*

Based on Figure 3, the temperature profile shows a linear increase in %yield. At 80°C the yield is 15.71%, increasing to 15.91% at 90°C. At 100°C the yield reaches 15.96%, followed by 16.04% at 110°C, and 16.11% at 120°C. For the evaporation temperature versus mass yield of powdered palm sugar (%w/w), the profile indicates relatively stable yields around 95%, with minor fluctuations. At 80°C, the yield is 95.41%. It slightly decreases to 95.03% at 90°C, increases to 95.14% at 100°C, and reaches an optimum yield of 95.66% at 110°C. However, at 120°C the yield drops to 94.78%. This pattern suggests an optimal evaporation temperature of 110°C for palm sugar crystallization, where crystal separation efficiency is highest. The decrease at 120°C is likely due to thermal degradation or caramelization of sugars, which reduces the amount of recoverable crystalline product.

The reduction in yield at 120°C is likely caused by thermal degradation and caramelization of sucrose in palm sap. Excessive heating can cause sucrose inversion into glucose and fructose. These monosaccharides have lower melting points and are more prone to forming caramel and humins (dark, non-crystalline materials). This reduces the amount of sucrose available for crystallization and produces sticky by-products that hinder separation, lowering the final yield of powdered sugar [5].

The evaporation process shows that yield increases linearly with temperature. This may be influenced by water content and sugar concentration in the sap. Yield represents the ratio of production output to input, indicating production efficiency [6]. According to Martunis (2012), lower temperatures result in less water evaporating, producing higher yield [7]. This implies that higher water content can increase calculated yield. However, the experimental results show that yield increases with temperature. This may indicate that the sugar content in the palm sap decreases during the process, influencing the yield trend.

3.2 Effect of Evaporation Temperature on the Moisture Content of Ant Sugar Produced

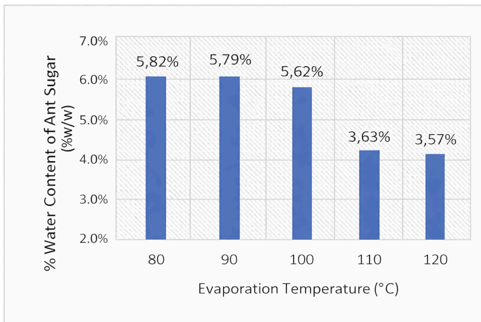


***Figure.* 4** The Effect of Evaporation Temperature on Water Content

Figure 4 shows that increasing the evaporation temperature consistently reduces moisture content. Moisture decreases from 5.82% at 80°C to 5.79% at 90°C, 5.62% at 100°C, then drops sharply to 3.63% at 110°C and reaches the lowest value, 3.56%, at 120°C. This confirms a linear relationship: higher temperature results in lower moisture content. The main factors affecting the moisture content of palm sugar include cooking, drying, packaging, and storage. During cooking, water evaporates from the sap, lowering moisture content and increasing solid concentration [8].

In drying theory, moisture content is influenced by the evaporation rate. Faster evaporation leads to lower final moisture. The evaporation rate depends on the difference in vapor pressure (ΔP) between the material surface and the surrounding air. A larger ΔP increases the driving force for evaporation. Higher drying temperatures, higher airflow, or lower relative humidity all increase ΔP and accelerate moisture removal.

3.2 Effect of Evaporation Temperature on the Ash Content of Ant Sugar Produced

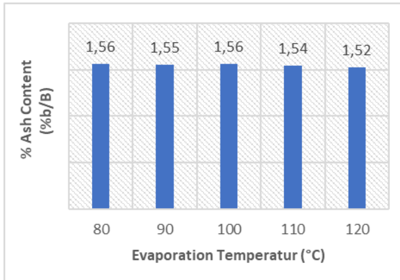


***Figure.* 5** The Effect of Evaporation Temperature on the Ash Content of Palm Sugar

Ash content represents the mineral level in a material, consisting of organic and inorganic salts. It is also an indicator of processing cleanliness. Based on Figure 5, ash content shows small fluctuations across temperatures. At 80°C the ash content is 1.56%, slightly decreasing to 1.55% at 90°C. It rises again to 1.56% at 100°C, then drops to 1.54% at 110°C and to 1.52% at 120°C. The variations are minor, only around 0.01%–0.04%. The low ash content is due to the raw material used being pure palm sap without the addition of preservatives or other additives. The mineral content of a material can influence ash content, the processing method, or the preservatives used [7]. Additionally, the presence of additives in the palm sap used, whether for preservation purposes or to improve characteristics, can also increase the ash content of the resulting palm sugar [8].

Ash levels are influenced by the mineral composition of the raw materials, processing steps, and any additives used [9]. Higher ash content can result from inorganic minerals such as phosphates, carbonates, chlorides, sulfates, and nitrates. Additives in palm sap, used for preservation or improving product characteristics, may also increase ash content [10]. In this study, ash content remains low. The highest values (1.56%) are observed at 80°C and 100°C. The low ash levels are due to the use of pure palm sap without preservatives or additional ingredients.

3.3 The Effect of Evaporation Temperature on the Percentage of Reducing Sugars in Ant Sugar Produced

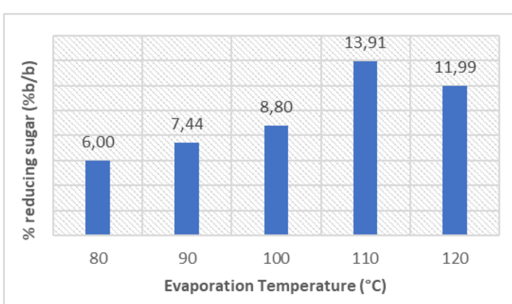


Figure. 6 The Effect of Evaporation Temperature on the Percentage of Reducing Sugars in Palm Sugar

Based on Figure 6, the reducing sugar content in palm sugar production shows noticeable changes as temperature increases. At 80°C, the reducing sugar level is still low (6%) because sucrose hydrolysis has not yet occurred efficiently. As the temperature rises to 90°C, 100°C, and 110°C, reducing sugars increases to 7.44%, 8.8%, and 13.91%. This is due to accelerated thermal hydrolysis, where higher temperatures break glycosidic bonds and convert sucrose or polysaccharides into simpler sugars such as glucose and fructose. Temperatures between 90°C and 110°C enhance thermal hydrolysis [11]. At 120°C, the reducing sugar content decreases to 11.99%. This drop is likely caused by caramelization and Maillard reactions. At high temperatures, reducing sugars degrade and form caramel compounds or other non-reducing degradation products [11]. These reactions consume reducing sugars, resulting in lower measured values. According to Sakri (2012), the breakdown of glycosidic bonds due to heating causes non-reducing sugars (sucrose) to be broken down into reducing sugars such as glucose and fructose [9].

3.4 Effect of Evaporation Temperature on Sucrose Percentage in Ant Sugar Produced

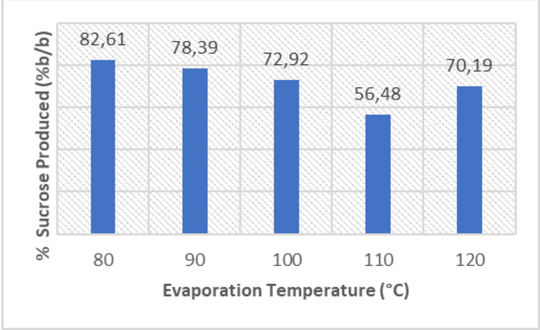


Figure. 7 The Effect of Evaporation Temperature on the Sucrose Content of Palm Sugar

Figure 4.8 shows that sucrose content decreases as temperature increases. At 80°C, sucrose is still high (82.61%), but it drops steadily to 78.39% at 90°C, 72.92% at 100°C, and reaches the lowest point at 110°C with 56.48%. This trend indicates that higher temperatures accelerate sucrose hydrolysis (inversion) into glucose and fructose. According to Eggleston and Monge (2005), temperatures above 80°C significantly increase the sucrose hydrolysis rate, especially under acidic conditions typical in palm sugar processing. Interestingly, at 120°C the sucrose content rises again to 70.19%. This suggests that competing reactions at high temperature—such as degradation of reducing sugars—may temporarily reduce the extent of sucrose breakdown, leading to a higher measured sucrose level.

Research (Kudra and Hill, 2017) in Food Chemistry shows that the presence of potassium and magnesium ions can modify the thermal stability of sucrose [10]. The results showed a decrease in sucrose content as the temperature increased. According to Susanto et al. (2018), heating nira above 80°C causes a 35-40% decrease in sucrose within 60 minutes due to accelerated hydrolysis [12]. The inversion reaction is also accelerated by the natural acidic conditions of nira (pH 5.5-6.5) and mineral content.

3.5 Effect of Temperature on the Color, Size, and Texture of Palm Sugar

***Table.* 1** *The Effect of Evaporation Temperature on Color, Size, and Texture*

T (°C)	Color	Gambar	Size (mm)	Texture
80	Brown		1.28	Crumbly
90	Brown		1.22	Crumbly
100	Brown		1.3	Crumbly
110	Brown		1,32	Hard
120	Brown		1.33	Hard

The particle size of palm sugar varies across temperatures. At 80°C and 90°C, the average crystal diameter is 1.28 mm. The size increases slightly at higher temperatures: 1.30 mm at 100°C, 1.32 mm at 110°C, and 1.33 mm at 120°C. According to SNI 3743:2021, the maximum allowable crystal size for palm sugar is 1.41 mm. All results in this study remain below this limit. Variations in crystal size can be influenced by the crystallization process. The faster stirring produces smaller, more uniform crystals, while slower stirring results in larger crystals. Temperature also plays an important role: higher temperatures slow down crystal growth, which can lead to larger crystal formation [14]. This aligns with the findings, where higher temperatures tend to produce slightly larger crystals.

Based on the quality requirements of SNI 3743:2021, the maximum diameter of palm sugar crystals is 1.41 mm. Several factors can cause the discrepancy in this research with the quality requirements of SNI 3743:2021 [13]. The stirring speed during crystallization determines the size of sugar crystals [2]. Intensive stirring can produce small and uniform sugar crystals, while slow stirring tends to produce larger crystals. In addition to stirring, the evaporation temperature also affects the size of sugar crystals. Based on previous research, high temperatures can cause slower crystal growth, resulting in larger crystals [8].

The brown color of granulated sugar is caused by the Maillard browning reaction and caramelization, which produce melanoidin pigments (brown pigments). The heating process can cause the Maillard reaction between sugar and amino acids in the palm sap, resulting in a brown color [2]. An incomplete browning reaction causes the overly pale color of palm sugar. The browning reaction that occurs during palm sugar production is caramelization.

4 Conclusion

The effect of temperature (80, 90, 100, 110, and 120°C) on the atmospheric-pressure evaporation crystallization process shows that higher temperatures increase the %yield, reaching the highest value of 16.11% at 120°C. Meanwhile, moisture content decreases, reaching 3.57% at 120°C. The palm sugar becomes darker in color and harder in texture as the temperature increases. Ash content remains stable at around 1.5%. Reducing sugars increase with temperature, reaching the highest level (13.91%) at 110°C, while sucrose content decreases, with the lowest value (56.48%) also occurring at 110°C.

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