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# Influence of Temperature and Stirring Duration on the Solubility Kinetics of Palm Sugar (*Arenga Pinnata*) in Water: Implications for Food Processing Efficiency

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**ABSTRACT**

*Palm sugar (Arenga pinnata) is widely used in traditional and industrial food processing, where its solubility plays a crucial role in determining product consistency and efficiency. However, most previous studies have focused on the solubility of refined cane sugar, leaving limited understanding of how temperature and stirring conditions affect the dissolution behavior of palm sugar, which has a more complex composition. This study aims to examine the effect of temperature, solute mass, and stirring duration on the solubility of palm sugar in water. A laboratory-based experimental method was employed, varying temperature (50°C, 75°C, 100°C), sugar mass (20 g and 40 g), and stirring duration (1 and 2 minutes). In general, the findings indicate that higher temperature accelerates the dissolution rate, while greater solute mass extends dissolution time. These results confirm temperature as the dominant factor influencing dissolution kinetics. The implications of this study include improving household practices for faster sugar preparation, optimizing processing efficiency in small-scale food industries, and contributing to food science education by providing an applied example of solubility principles.*

Keywords: *Brown sugar, Temperature, Solubility, Dissolving Tme*

 

## 1. INTRODUCTION

Arenga palm sugar, derived from the sap of *Arenga pinnata*, is a natural sweetener widely used in household and traditional food processing, particularly in Southeast Asia.[1,2] Beyond sweetness, it enhances color, aroma, and flavor in food products.[3] Solubility is a key factor affecting texture, taste uniformity, and processing efficiency, including foam stability in meringues.[4,5] With growing demand for natural ingredients, understanding arenga sugar solubility is of increasing relevance in applied food science.

Previous studies have examined factors such as temperature, stirring duration, and solute mass on sugar solubility.[6–10] However, most research has focused on refined cane sugar or arenga sugar partially, without examining the simultaneous interaction of multiple factors. Some studies have indicated that increasing temperature accelerates sugar solubility.[11,12] Research by Mendoza et al. [13] also demonstrated that temperature influences arenga sugar solubility during crystallization. Various methods, such as spray drying, membrane technology, and vacuum drying, have been identified as potential approaches to enhance arenga sugar solubility.[14] Although previous studies have generally shown that sugar solubility increases with rising temperature, as observed in glucose and lactose [15], these studies were limited to single-factor effects and did not consider the simultaneous interaction of temperature, solute mass, and stirring duration on arenga sugar solubility. This indicates a research gap that needs to be addressed to fully understand the factors affecting sugar solubility at both laboratory and small-scale industrial levels.

Furthermore, increasing solute mass tends to prolong the time required for dissolution, as the dissolution rate is usually determined by the surface area of the solute particles. Smaller particles have a larger surface area and dissolve faster due to more intensive interaction with the solvent.[16,17] Solute mass is also a critical factor in determining the dissolution rate. A study by Sholihah et al. [17] showed that increasing sugar mass can extend the dissolution time; however, this study did not systematically examine the interaction with temperature. This highlights a limitation in the literature regarding the combined effects of temperature and solute mass on arenga sugar solubility.

Based on a literature review, most previous studies have only examined the effects of temperature [18–21] or solute mass [22–24] separately, without considering their interaction on arenga sugar solubility. This presents an important gap, given that arenga sugar solubility in real-world scenarios is simultaneously influenced by temperature, mass, and stirring duration.[25,26] Research addressing this gap is necessary to provide a scientific basis for optimizing arenga sugar processing, both at household and small industrial scales, while also offering an applied example of solubility principles in science education.

This study aims to comprehensively analyze the effects of temperature and sugar mass on the solubility of arenga sugar in water. The novelty of this research lies in the integration of temperature and sugar mass variables in a single experiment, as well as the determination of optimal dissolution time, which has rarely been conducted previously. The findings are expected to provide practical contributions for improving arenga sugar processing efficiency and to enrich the scientific literature on solid–liquid solubility.

## 2. EXPERIMENTAL

 

### *2.1. Chemicals, Equipment and Instrumentation*

The main ingredients used in this study are sugar palm (Arenga pinnata) and coconut (Cocos nucifera). Brown sugar contains various organic compounds such as sucrose ($C_{12}H_{22}O_{11}$), glucose ($C_6H_{12}O_6$), fructose ($C_6H_{12}O_6$), and small amounts of organic acids such as acetic acid ($CH_3COOH$) and formic acid (HCOOH). It comes from local markets without a particular trademark.

Devices used include a glass measuring 100 ml and 250 ml, bunsen for heating, analog thermometers (0-100°C), analogous scales with a precision of 0.0001 g, a stainless steel knife for cutting materials, and a digital stopwatch for time measurement. All glass and metal tools are cleaned first before being used to ensure accuracy in measurement.

### *2.2. Research Procedure*

The study began with a test of three types of brown sugar in plain water. 120 ml of water, in three cups of measurement, is given a single type of brown sugar. All three varieties of sugar are then stirred for two minutes with a spoon. After the grinding process, an observation was made about how the extraction was made, and it was found that sugar palm has the greatest flakes and the longest the two varieties of sugar.

Next, there was a test of sugar palm with two mass variations and a hard time of composition, which was 20 grams for 1 minute and 40 grams for 2 minutes. For the first treatment, each of the three ten-ounce (20 g) sugar slices was weighed using analytic scales. The water is heated to a temperature of 50°C, 70°C, and 100°C separately, and then each of the hot water is poured into a measuring glass that has been filled with sugar slices. Each solution is then stirred for one minute and the remaining undissolved sugar is reweighed for analysis.

On second treatment, three ten-ounce (40 grams) of sugar palm was weighed and tested with the same procedure, but the extended length of the mixture was 2 minutes. Individual chunks of sugar are dissolved in 50°C, 70°C, and 100°C, and then stirred for two minutes and reweighed the undissolved remains. All data of pelaration are collected for further analysis to see how the temperature, mass, and time affects the sugar palm's salinity level.

## 3. RESULTS AND DISCUSSION

### *3.1. Initial Solubility Test in Cold Water*

The initial solubility test was conducted by dissolving 20 g of each sugar: regular brown sugar, palm sugar, and coconut sugar, into 120 ml of water at room temperature for 2 minutes. The remaining sugar mass after stirring is shown in Table 1.

**Table 1.** Remaining sugar mass after 2-minute stirring in cold water

| Brown Sugar Names | Initial Mass | Water volume | Stirring Time | Final Mass |
|---|---|---|---|---|
| **Regular Brown Sugar** | 20 grams | 120 ml | 2 minute | 14 grams |
| **Palm Brown Sugar** | 20 grams | 120 ml | 2 minute | 16 grams |



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| | | | | |
|---|---|---|---|---|
| **Coconut Brown Sugar** | 20 grams | 120 ml | 2 minute | 15 grams |

Based on the measurements presented in Table 1 and Figure 1, under standard conditions (initial mass of 20.0 g; 120 mL of water; stirring for 2 minutes; room temperature), the dissolved fractions were as follows: common brown sugar 6 g (30%), palm sugar 4 g (20%), and coconut sugar 5 g (25%). Using the final mass in Table 1 defined as the undissolved mass, these results indicate that common brown sugar exhibited the highest initial dissolution within this short time interval, whereas palm sugar showed the lowest initial dissolution.

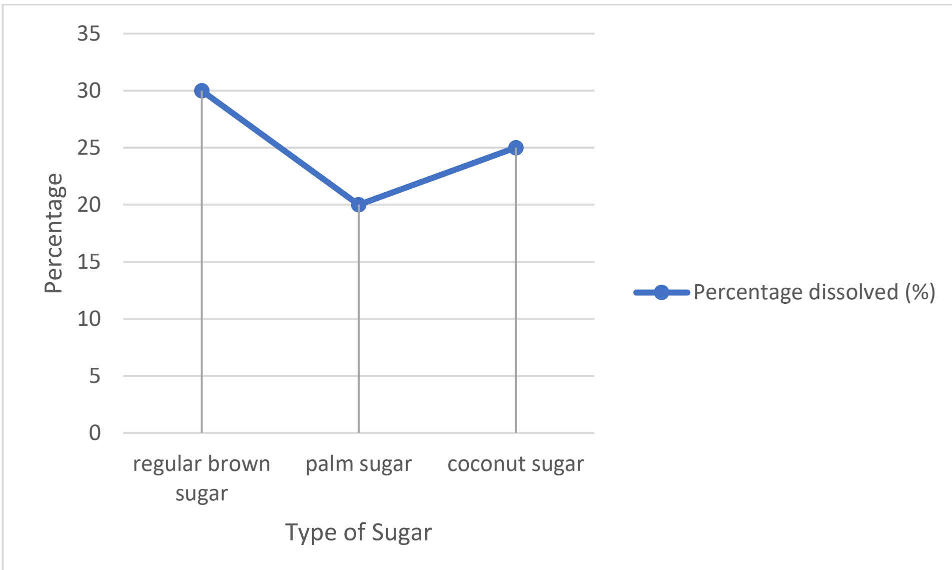


**Figure 1.** Percentage of dissolved mass after 2 minutes of stirring (120 mL, room temperature)

This difference is most likely determined by the physicochemical properties of the samples, including particle size and crystal morphology, sugar composition (ratio of sucrose to reducing sugars), mineral content (ash), as well as moisture content and degree of amorphousness. Finer particles or more amorphous samples tend to exhibit higher dissolved fractions within a short time due to larger surface area and better permeability to water.[27,28] Conversely, according to Aoki et al.[29] and Verma et al.[30] the presence of more crystalline fractions or insoluble impurities reduces the measured dissolved mass during short-duration stirring.

*3.2. Effect of Temperature on Dissolving 20 g of Palm Sugar*

This experiment investigated the dissolution of 20 grams of palm sugar in 120 mL of water with 1-minute stirring at three different temperatures: 50°C, 75°C, and 100°C. The aim was to examine how temperature influences the dissolution rate of a fixed quantity of sugar.

The results in Table 2 indicate that at 50°C, 6 grams of sugar remained undissolved, requiring 2.24 minutes for complete dissolution. At 75°C, the remaining sugar decreased to 4 grams with a dissolution time of 1.57 minutes. At 100°C, almost all sugar was dissolved, leaving only 3 grams, with the shortest dissolution time of 1.45 minutes. These findings demonstrate that higher temperatures significantly enhance the dissolution rate. Increasing temperature raises the kinetic energy of water molecules, improving solute-solvent interactions and accelerating the diffusion of sugar into the solvent.[31] Moreover, smaller solute mass reduces the resistance to dissolution, enabling faster solute dispersion. The combination of higher temperature and reduced solute mass shows a synergistic effect on solubility kinetics.

**Table 2.** Dissolution Kinetics of 20 g Palm Sugar at Different Temperatures with 1-Minute Stirring

| Temperature | Water Volume | Final Mass | Time to Complete Dissolution |
|---|---|---|---|
| **50°C** | 120 ml | 6 grams | 2,24 minute |
| **75°C** | 120 ml | 4 grams | 1,57 minute |
| **100°C** | 120 ml | 3 grams | 1,45 minute |

From a practical perspective, these findings suggest that the efficiency of sugar processing can be improved by optimizing both temperature and solute quantity. Utilizing higher temperatures can accelerate the dissolution process, thereby reducing the time required for complete solute dispersion, which may enhance throughput and reduce energy consumption associated with prolonged stirring. However, careful temperature control is necessary to prevent thermal degradation of the juice and loss of sucrose.[32] Furthermore, advances in thermal processing, such as variable retort temperature profiles (VRTPs), have been shown to optimize operations by shortening processing times and lowering energy use while maintaining product quality.[33]

### *3.3. Effect of Temperature on Dissolving 40 g of Palm Sugar*

An experiment was conducted to investigate the solubility of 40 grams of palm sugar in 120 ml of water at three different temperatures: 50°C, 75°C, and 100°C. The stirring process was maintained for 2 minutes, and two parameters were recorded: the final mass of undissolved sugar and the total time required for complete dissolution. The results are presented in Table 3.

**Table 3.** Dissolution Kinetics of 40 g Palm Sugar at Different Temperatures with 2-Minute Stirring

| Temperature | Water Volume | Final Mass | Time to Complete Dissolution |
|---|---|---|---|
| **50°C** | 120 ml | 11 grams | 4.05 minute |
| **75°C** | 120 ml | 9 grams | 3,40 minute |
| **100°C** | 120 ml | 4 grams | 3,10 minute |

The data indicate a clear relationship between water temperature and the dissolution rate of palm sugar. As the temperature increased, the remaining mass of undissolved sugar after 2 minutes decreased, and the total time required for complete dissolution was reduced. At 50°C, 11 grams of sugar remained undissolved, requiring 4.05 minutes for full dissolution. Increasing the temperature to 75°C reduced the undissolved mass to 9 grams, with a total dissolution time of 3.40 minutes. At 100°C, only 4 grams of sugar remained undissolved, and the total dissolution time decreased to 3.10 minutes.



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According to several studies, the accelerated dissolution at higher temperatures is primarily caused by the increase in kinetic energy of water molecules, which results in more frequent and energetic collisions that enhance solute-solvent interactions and molecular diffusion.[34–37] Mohan et al.[38] have also emphasized that heat transfer, pressure, and the nature of solute-solvent interactions can further influence the dissolution process. These observations are consistent with classical solubility theory, which predicts that solute dissolution generally improves with temperature due to enhanced molecular motion and reduced viscosity of the solvent.

### *3.4. Effect of Temperature on Final Mass and Dissolution Time of Palm Sugar*

The graphs below illustrate the results of the study on the effect of temperature on two key variables in the dissolution process: the final mass of the solute and the time required for complete dissolution. The first graph depicts how temperature influences the final mass of palm sugar at two different initial masses, namely 20 grams and 40 grams. The second graph shows the relationship between temperature and the time needed for complete dissolution at the same two solute masses. Together, these graphs provide a clear picture of the important role that temperature plays in determining the efficiency and speed of the dissolution process.[39]

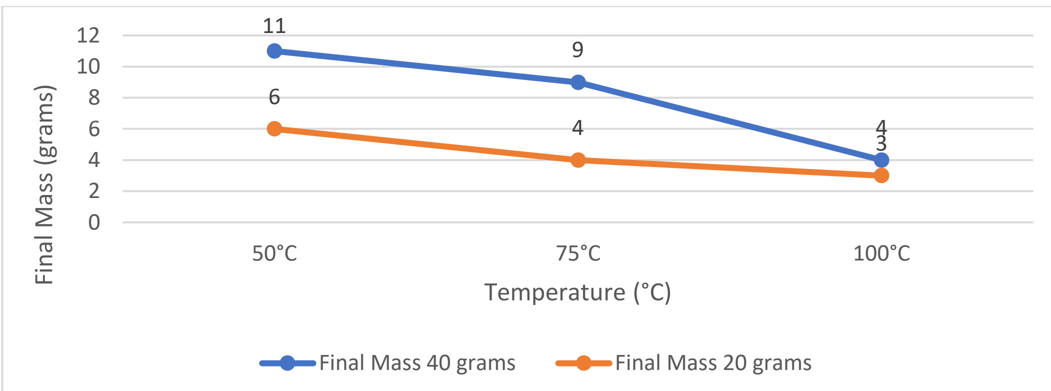


**Figure 2.** Effect of temperature on the remaining mass of palm sugar at two initial masses

Based on Figure 2, it can be observed that increasing water temperature significantly affects the final mass of palm sugar after the dissolution process. For the initial mass of 40 grams, the remaining sugar decreased from approximately 11 grams at 50°C to 8.5 grams at 75°C, and further dropped to 3.5 grams at 100°C. A similar trend is seen for the initial mass of 20 grams, although the absolute values are smaller. The greater reduction in remaining sugar at higher temperatures indicates that solubility increases with temperature, which can be explained by the higher kinetic energy of water molecules. Increased kinetic energy accelerates molecular motion, enhances the frequency and intensity of collisions with sugar molecules, and thus promotes diffusion and solute-solvent interactions.[40]



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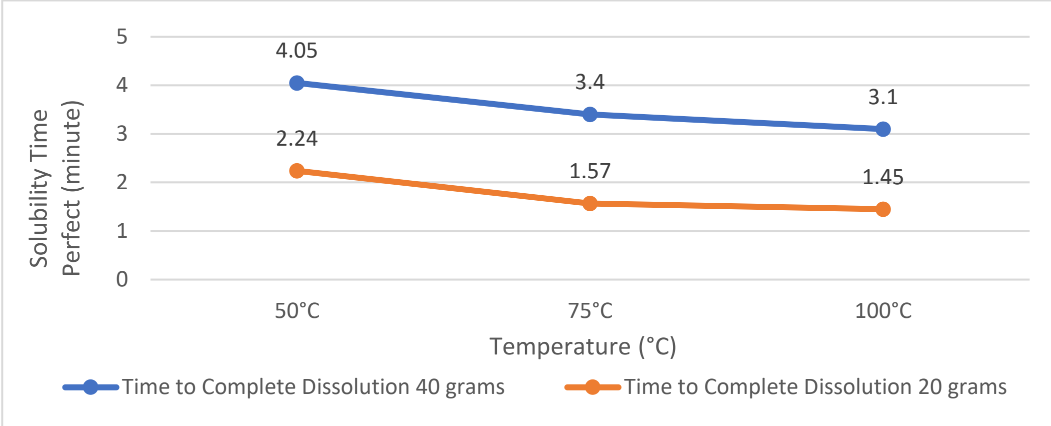


**Figure 3.** Effect of temperature on the time required for complete dissolution at two initial masses

Figure 3 illustrates the relationship between temperature and the time required for complete dissolution of palm sugar at two initial masses: 20 grams and 40 grams. The horizontal axis represents water temperature (50°C, 75°C, and 100°C), while the vertical axis shows dissolution time in minutes. For the 40-gram sample, the dissolution time decreased from approximately 4 minutes at 50°C to 3.2 minutes at 100°C. Similarly, for the 20-gram sample, the dissolution time reduced from around 2.3 minutes at 50°C to 1.6 minutes at 100°C. These results indicate that higher temperatures accelerate the dissolution process by enhancing molecular motion and solute-solvent interactions. In addition, larger solute masses require longer times to dissolve compared to smaller masses at the same temperature.[41] Therefore, Figure 3 reinforces the conclusion that both temperature and initial solute mass are critical factors affecting the rate and efficiency of palm sugar dissolution.

## 4. CONCLUSION

Based on the results of the research we have done, it can be concluded that water temperature, time and mass of palm brown sugar have a significant effect on the speed of sugar dissolution in water. The solubility test shows that the higher the water temperature, the faster the brown sugar dissolves. This can be seen from the comparison of dissolving time at 50°C, 75°C, and 100°C, both at a sugar mass of 20 grams and 40 grams. In addition, smaller masses of sugar also require shorter dissolving times than larger masses under the same temperature conditions. For example, at 100°C, sugar with a mass of 20 grams dissolved in 1.45 minutes, while the mass of 40 grams took 3.10 minutes.

From this finding, it can be concluded that the optimal temperature to accelerate the dissolution process is 100°C, where a mass of 20 grams of sugar dissolves in 1.45 minutes, while a mass of 40 grams takes 3.10 minutes. From these findings, it can be concluded that the optimal temperature to accelerate the dissolving process is 100°C, and smaller masses of sugar tend to dissolve more efficiently. The results of this study are important to be applied in the sugar dissolving process in the food industry or household, especially to obtain time efficiency and optimal results.



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