Chemical and thermal properties of sugar palm fruits (*Arenga pinnata*) at different maturity levels

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Abstract. *Arenga pinnata* plant produces a large amount of fruit, both young and matured. However, the utilization of sugar palm fruit remains limited. Young sugar palm fruit is generally processed into sweets, while matured sugar palm fruit is often discarded as waste. To optimize the utilization of sugar palm fruit, this study aimed to analyze its chemical composition and thermal properties. The chemical composition included water content, ash, fat, protein, carbohydrates, and crude fiber, while the thermal properties were analyzed using differential scanning calorimetry (DSC) to measure the melting temperature and glass transition temperature. The results showed that matured sugar palm fruit had a lower water content (44.43%) and higher amounts of carbohydrates (53.07%) and crude fibre (12.30%). Additionally, matured sugar palm fruit exhibited a higher melting temperature (189.410^{0}C) and a glass transition temperature (148.130^{0}C). In contrast, young sugar palm fruit had a higher water content (88.169%) and a higher fat content (1.08%) compared to matured palm fruit (0.44%). Young sugar palm fruit also had a lower melting temperature (171.81°C) and glass transition temperature (137.85°C). This study concluded that the ripening stage significantly effects the chemical composition and thermal properties of sugar palm fruit.

1 Introduction

Arenga pinnata, known as sugar palm fruit, is a type of palm plant that grows abundantly and produces a large amount of young and matured fruit. However, the utilization of sugar palm fruit remains very limited [1]. In Indonesia, the community mostly processes young sugar palm fruit into a sweet called kolang-kaling, while the matured sugar palm fruit is often underutilized and discarded as waste [2]. Sugar palm fruit, both young and mature, contains galactomannan. Galactomannan is a heteropolysaccharide composed of galactose and mannose [3]. Several studies have shown that fruit containing galactomannan can be used in various applications such thickeners, stabilizers, and emulsifiers [4]. To optimize its utilization, a deeper understanding of the chemical composition and thermal properties at different stages of ripeness is required. Proximate analysis examines the chemical composition, particularly the moisture, ash, fat, protein, carbohydrate, and crude fiber content. Meanwhile, differential scanning calorimetry (DSC) can be used to assess the thermal properties of sugar palm fruit, such as melting temperature and glass transition, which are influenced by the fruit's ripeness.

This research aims to analyze the chemical composition and thermal properties of sugar palm fruit at different stages of ripeness. The results of this study are expected to provide a deeper understanding of the chemical composition and thermal properties of both young and mature sugar palm fruit, enabling their utilization as high-value raw materials in the food industry and other applications.

2 Materials and Methods

2.1 Materials

Sugar palm fruit was collected from Bogor, West Java, Indonesian farmers. The sugar palm fruit was boiled for 3 hours and then peeled to remove its thin skin. Young and matured sugar palm fruits were distinguished by the color of their skin, which was yellow for young fruits and black for matured sugar palm fruits. The peeled fruit was washed thoroughly and dried using a freezer dryer.

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2.2 Methods

2.2.1 Chemical Analysis

Moisture, ash, fat, protein, carbohydrate, and fiber contents were determined using standard procedures established by the Association of Official Analytical Chemists (AOAC) [5].

2.2.2 Differential Scanning Calorimetry (DSC) Analysis

Thermal characteristics of sugar palm fruits were analyzed using a DSC 60 (Shimadzu, Tokyo, Japan). A 5-10 mg sample of both matured and young fruits was placed in a specialized sample container (pan cell No 201-52943) and then sealed tightly. The DSC instrument was operated under a flow of nitrogen gas and set to a heating rate of 10°C per minute, starting from a temperature of -10°C to 300°C. Data were acquired using the TASYS software (Shimadzu Corporation, Kyoto, Japan), and the results were presented as a thermogram. The enthalpy was calculated based on the peak area between the initial and final temperatures. Scanning was performed twice to assess the presence of thermoplastic potential and to clarify the analysis of the glass transition temperature (Tg) [4]

2.2.3 *Statistical Analysis*

This study used a Completely Randomized Design (CRD) with two treatment replicates. The resulting data were analyzed using an Analysis independent t-test, employing IBM SPSS Statistics 27 software. The analyses were conducted with a significance level (alpha) of 5%.

3 Results and Discussions

3.1 Proximate analysis

The proximate analysis results, which include moisture content, ash, fat, protein, carbohydrate, and crude fiber content in both matured and young sugar palm fruits were presented in Table 1.

Table 1. Proximate composition of young and matured sugar palm fruits

Proximate Parameter	Young Sugar Palm Fruits (%)	Matured Sugar Palm Fruits (%)
Moisture	88.16 ± 1.76^{b}	44.42 ± 6.16^{a}
Ash	0.31 ± 0.10^{a}	0.22 ± 0.10^{a}
Fat	1.07 ± 0.23^{b}	0.44 ± 0.34^{a}
Protein	0.10 ± 0.00^{a}	1.43 ± 0.13^{b}
Carbohydrate	10.54 ± 1.37^{a}	53.06 ± 5.59^{b}
Crude Fiber	1.96 ± 0.84^{a}	$1.29^{a} \pm 0.77^{b}$

Values are presented as mean ± standard deviation (n=4). Superscripts with different letters indicate significant differences between sample temperatures, as determined by the independent T-test ($P \leq 0.05$).

3.1.1 Moisture content

As shown in **Table 1**, there was a significant difference in water content between young and matured sugar palm fruits. Young sugar palm fruit had a water content of 88.16%, which indicated its developmental stage. During this stage, the cells actively perform metabolism, which requires a large amount of water to support processes such as cell division, growth, and nutrient storage [6]. The matured sugar palm fruit in Table 1 appears to have a higher water content of 44.42%. As the sugar palm fruit ripens, its water content decreases, indicating a transition to the ripening process, which includes the formation of important organic compounds such as sugars, fibers, and bioactive elements. This ripening process naturally causes water loss due to evaporation. Conversely, younger fruits with higher moisture content are more susceptible to microbial damage [7]

3.1.2 Ash content

The Analysis showed that young sugar palm fruits had a higher ash content of 0.31% compared to matured sugar palm fruits at 0.22%, as shown in **Table 1**. The ash content analysis was conducted to evaluate the presence of organic and inorganic minerals, along with other residues. The process of ripening sugar palm fruit from young to matured accumulated more minerals, such as potassium, calcium, magnesium, and phosphorus, thereby contributing to a higher ash content. When the fruit matured, these minerals were redistributed throughout the plant, either transferred to other parts or used in metabolic processes. This redistribution causes a lower ash content in matured fruit. It was discovered that, as the fruit ages, its mineral content decreases due to physiological processes such as nutrient translocation [8].

3.1.3 Fat content

The results of the fat content research conducted on young and matured sugar palm fruits showed significant findings. The fat content of young sugar palm fruit was 1.07%, which was higher than the 0.44% in matured sugar palm fruit, as shown in Table 1. The fat content was higher in young sugar palm fruit because young fruit stored energy to support its growth and development and had a higher water and organic compound content, as it had not attained full maturity. On the other hand, matured sugar palm fruit has a lower fat content due to the ripening process, during which fats broke down into other substances like sugars or were used in the fruit's metabolic processes. It was also noted that water content plays a role in the fat content differences. Since young fruit tended to have more water, it affects the concentration of fat [9]. In contrast, matured fruit underwent major biochemical changes, leading to a reduction in fat as enzymes converted lipids into energy or other compounds.

3.1.4 Protein content

Research on protein levels showed that young palm fruit had lower protein content compared to matured palm fruit. Specifically, the protein level in young palm fruit was 0.10%, while in matured palm fruit, it was 1.43%, as shown in **Table 1**. This difference could be explained by the fact that young fruits were still in the early stages of development. When the fruit was young, a lot of energy and resources were used to build cellular structures and store energy reserves such as fat and carbohydrates, rather than focusing on protein production. In addition, fruit metabolic activity at this stage

was more focused on cell division and tissue formation, which meant that protein synthesis had not yet reached optimal levels. In matured palm fruit, the increase in protein levels was due to a higher rate of protein synthesis, which was necessary for the physiological function of the fruit. These functions include producing enzymes required for the ripening process and for defending against environmental stress [10]. During ripening, the fruit also accumulated certain nitrogen compounds, such as amino acids, which were then used to synthesize proteins, contributing to the rise in protein content seen in matured fruit [11]

3.1.5 Carbohydrate content

Carbohydrates content data analysis carried out on young and matured palm fruit showed a significant difference. Young palm fruit had a carbohydrate content of 10.54%, while matured sugar palm fruit had 53.06% as shown in **Table 1**. This difference in carbohydrate content occurred because, when the fruit ripened, metabolic processes shifted, increasing carbohydrate storage, which was important for the development of energy and plant structure. In palm fruit, the carbohydrates contained in it were widely used for metabolic activities and the development of cellular structures. The same results were also obtained in this study [12]

3.1.6 Crude Fiber Content

Fiber content data analysis was carried out on young and matured palm fruit, and the results obtained showed significant differences, as shown in Table 1. Young palm fruit had a fiber content of 1.96% while matured palm fruit had 2.29%. The difference in crude fiber was caused by the ripening process, which included the evolution of the cell wall structure. As the palm fruit grew, it underwent lignification and the accumulation of fibrous components, including cellulose and lignin, within its cell walls. This process strengthens the plant's tissues and prepared the fruit for germination. conversely, young fruits had not completely established their fibrous tissues, resulting in reduced fiber content [10]

3.2 Melting Temperature

Analysis data using differential scanning calorimetry (DSC) on young and matured sugar palm fruits showed an endothermic process as seen in **Fig 1**. This endothermic process involves the absorption of heat by the sample from the surrounding environment during the thermal transition. The peaks observed in the DSC graph in **Fig 1** indicated melting points and glass transitions. Based on the research findings, the melting temperatures of young and matured sugar palm fruit differed significantly ($p < 0.05$), as shown in **Table 2**

Table 2. Peak temperature DSC thermograms, enthalpy changes (ΔH), and glass transition temperature (Tg) sugar palm fruits

Parameter	Young Palm fruits	Matured Palm fruits
To (°C) Onset	170.34± 0.27[a]	188.46± 0.21[b]
Tp (°C) Peak	171.81 ± 0.84[a]	189.41 ± 1.41[b]
Te (°C) Endset	184.08± 0.21[a]	194.76 ± 0.63[b]
ΔH (J/g)	59.30[a]	47.10[a]
Tg (°C)	137.85 ± 1.52[a]	148.13 ± 1.00[b]

Values are presented as mean ± standard deviation (n=2). Superscripts with different letters indicate significant differences between sample temperatures, as determined by the independent T-test ($P \leq 0.05$)

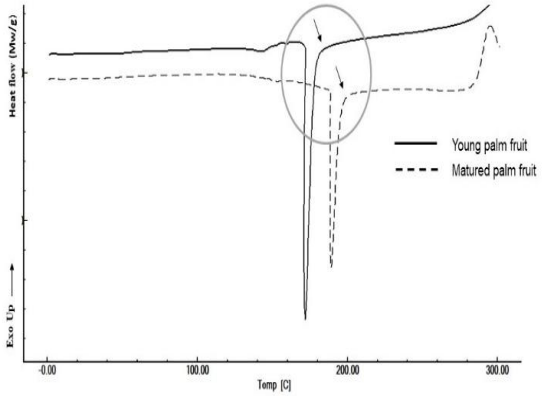

Fig. 1. DSC scans of the two analyzed sugar palm fruits obtained at a heating rate of 10^0C min^{-1} under a nitrogen atmosphere.

The differential scanning calorimetry (DSC) test conducted on young and matured palm fruits obtained data showing that the melting point of young palm fruits was lower at 171°C compared to the melting point of matured palm fruits at 189.4°C, as seen in **Fig 1 and Table 2.** The chemical composition and molecular structure of the young and matured sugar palm fruit caused the difference in melting temperature of sugar fruit. In young fruit, the structure was more semicrystalline [13] This resulted in a lower melting point because less energy was needed to break the molecular bonds. In addition, the high moisture content in young fruit also causes a decrease in melting temperature. This occurred due to the interaction between water molecules and starch, reducing thermal stability. Matured sugar fruit had a crystalline structure, making it more stable. This required more energy to melt, resulting in a high melting point of 189.4°C. In addition, the lower water content in matured fruit enhances thermal stability, resulting in an increased melting point [14].

3.3 Glass Transition (Tg) Temperature

Analysis data of glass transition temperature (Tg) using differential scanning calorimetry (DSC) on young and matured sugar palm fruits showed an endothermic process, as seen in **Fig. 2**

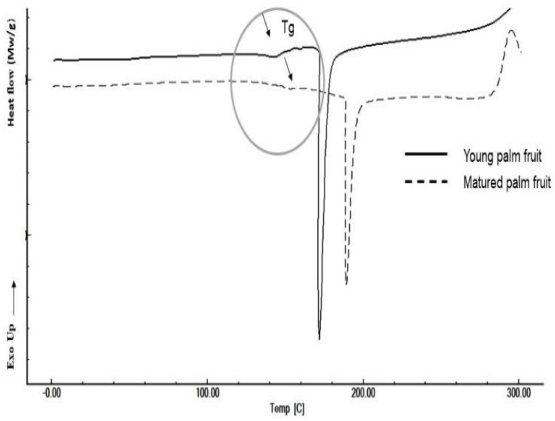

Fig. 2. DSC scans of the two glass transition analyzed sugar palm fruit obtained under nitrogen atmosphere at a heating rate of 10^0C min^{-1} under a nitrogen atmosphere

The analysis results showed that the chemical composition, molecular structure, and water content of palm fruit could cause the difference in Tg between young fruit and matured fruit. In matured fruit, the structure formed a more stable crystal structure. This additional stability means that the fruit required more energy to undergo the glass transition, resulting in a higher Tg of 148.13°C, as seen in **Table 2**.

Young sugar palm fruit had a semicrystalline structure [13], which means it requires less energy to achieve the glass transition. The Tg was lower, namely 137.85°C, as seen in **Table 2.** Lower water content in matured sugar palm fruit reduces the plasticizing effect of water on the molecular structure, thereby increasing Tg. In contrast, young fruit had more water, which acted as a plasticizer, reducing molecular interactions and lowering Tg. During the fruit ripening process, compounds such as sugar and fiber accumulate, thereby increasing intermolecular interactions, which will cause an increase Tg. When palm fruit is still young, it had lower sugar and fiber content, this weaker intermolecular interaction resulted in a lower Tg [15].

4 Conclusions

This study concluded that there were significant differences between young and matured sugar palm in both proximate and thermal analyses. In the proximate analysis, matured sugar palm fruit had a lower water content (44.42%) compared to young sugar palm fruit (88.16%). Additionally, matured sugar palm fruit exhibited higher amounts of carbohydrates (53.06%) and crude fiber (12.2%), while young sugar palm fruit had a higher fat content (1.07%) than matured sugar palm fruit (0.44%).

Based on the results of differential scanning calorimetry (DSC) analysis, matured sugar palm fruit showed a higher melting temperature (189.41°C) ($P \leq 0.05$) compared to young sugar palm fruit, which had a melting temperature (171.81°C). Furthermore, the glass transition temperature (Tg) of matured sugar palm fruit (148.13°C), while young sugar palm fruit had a lower Tg (137.85°C). The maturity of sugar palm fruit significantly influenced its proximate composition and thermal properties and utilization of sugar palm fruit for various applications. Further research is recommended to explore the potential of sugar palm fruit in industrial applications, particularly in food.

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