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Comparative Study of in Vitro Glycemic Index, Chemical Composition, and Organoleptic Properties of Palm Sugar *(Arenga pinnata* Merr.) Products

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A B S T R A C T

Palm sugar (Arenga pinnata Merr.) has strong potential as a natural alternative sweetener, thanks to its distinctive sensory properties and a lower glycemic index than white sugar. This study evaluated the in vitro glycemic index, chemical characteristics, and organoleptic properties of liquid, molded, and granulated palm sugar, using white sugar as a reference. The results showed that all palm sugar products had a low glycemic index (35–39), significantly lower than that of white sugar (GI 60), reflecting differences in sugar composition, mineral content, and physical structure. Organoleptic tests indicated good consumer acceptance, particularly for granulated palm sugar. Overall, this study highlights palm sugar's potential to support the development of healthier sweetener alternatives and value-added downstream products.

Contribution to Sustainable Development Goals (SDGs):
SDG 6: Clean Water and Sanitation
SDG 8 – Decent Work and Economic Growth
SDG 9 – Industry, Innovation, and Infrastructure
SDG 12: Responsible Consumption and Production.

1. INTRODUCTION

1.1. *Research Background*

Sugar consumption in Indonesia and globally continues to increase in line with changes in dietary patterns and modern lifestyles. White sugar derived from sugarcane remains the dominant sweetener due to its wide availability and relatively low price. According to the Ministry of Agriculture of Indonesia [1], the average per capita consumption of white sugar is projected to reach 5.371 kg in 2024. However, excessive consumption of refined sugar has been strongly associated with an increased prevalence of metabolic disorders, including diabetes mellitus, obesity, and metabolic syndrome [2]. These health concerns have intensified efforts to identify alternative sweeteners that are not only safer but also provide additional functional benefits.

Palm sugar, derived from the sap of the sugar palm (*Arenga pinnata* Merr.), is one of the natural sweeteners with high development potential in Indonesia. The sugar palm grows in 26 provinces, covering approximately 62,000 hectares, with sap yields ranging from 8 to 22 liters per tree per day [3]. This substantial production capacity supports the development of various downstream palm sugar products, including moulded, granulated, and liquid palm sugar. In addition to its characteristic flavour, palm sugar is reported to contain bioactive components, including proteins, organic acids, amino acids, vitamins, and minerals, which are generally absent in refined white sugar [4].

Moreover, palm sugar has been widely reported to have antioxidant activity and a lower glycemic index (GI) than white sugar. Antioxidant properties in palm sugar are mainly attributed to melanoidin compounds formed during thermal processing [5]. Previous Study reported that palm sugar exhibited antioxidant activity of 28.88%, whereas white sugar showed only 0.16% [6]. Despite these promising attributes, scientific evidence supporting palm sugar's health claims, particularly regarding its glycemic response, remains limited and fragmented.

1.2. Literature Review

Previous studies on palm sugar have primarily focused on production techniques, physicochemical characteristics, and basic nutritional composition. Previous Study [3], highlighted the potential of sugar palm sap as a raw material for various palm sugar products, including molded palm sugar, granulated palm sugar, and liquid palm sugar. [4] further demonstrated that palm sugar contains proteins, amino acids, and mineral components that are not present in refined sugar, reinforcing its nutritional advantage.

From a functional perspective, [6] provided evidence that palm sugar exhibits significantly higher antioxidant activity than sugarcane sugar. This activity has been linked to the formation of melanoidin compounds during heating and processing stages [5]. These findings support the notion that palm sugar may offer added health benefits beyond its role as a sweetener.

The glycemic index (GI) is a critical parameter used to evaluate the rate at which carbohydrate-containing foods raise blood glucose levels [7]. Foods with a high GI induce rapid postprandial glucose spikes, which are associated with metabolic health risks. Several studies have suggested that palm sugar may have a lower GI than white sugar; however, available data remain inconsistent and limited. Importantly, systematic and standardized comparisons of GI values among different palm sugar product forms, molded, granulated, and liquid palm sugar, are still scarce. Consequently, many claims regarding the health benefits of palm sugar lack robust quantitative validation.:

1.3. Research Objective

This Study aims to evaluate and compare the in vitro glycemic indices of various palm sugar products, including moulded, granulated, and liquid palm sugar. Additionally, this research aims to generate scientifically validated data to support health-related claims about palm sugar consumption. The findings are expected to strengthen downstream development, the competitiveness of Indonesian palm sugar products in both domestic and global markets, and standardisation.

2. MATERIALS AND METHODS

2.1. Time and Place

This research was conducted from October to December 2025 at the Kelomok Tani Mutiara Plantation, Labuah Gunung Village, Lima Puluh Kota District, West Sumatra. Laboratory analyses were carried out at the Laboratory of Chemistry, Biochemistry, and Agricultural Products, Department of Food Technology and Agricultural Products, and the Instrumentation Laboratory, Faculty of Agricultural Technology, Andalas University.

2.2. Materials and Equipment

The primary material used in this Study was fresh sugar palm sap obtained from local farmers in West Sumatra. Additional materials included distilled water, cooking oil, and liquid glucose. Chemicals used for in vitro glycemic index analysis consisted of α-amylase, amyloglucosidase, 0.5 M HCl, 0.1 M phosphate buffer (pH 6.5), DNS reagent, and glucose standards (0–1000 ppm).

The equipment used included sap-tapping tools, fine strainers, a heating stove, a wok, a thermometer, a wooden stirrer, palm sugar moulds, a freezer (−22°C), a digital balance, a 20-mesh sieve, and storage containers. Laboratory instruments included a water bath or incubator, test tubes, micropipettes, a vortex mixer, a hot plate, volumetric glassware, and a UV–Vis spectrophotometer.

2.3. Palm Sugar Preparation

Fresh palm sap was collected directly from sugar palm trees and filtered to remove impurities. The sap was processed within 90 minutes after tapping or stored at −22°C to prevent fermentation [8]

Liquid palm sugar was produced by heating the sap until the soluble solid content reached approximately 70 °Brix, with a small amount of cooking oil added to control foam formation. For molded palm sugar, heating was continued until the concentration reached approximately 90 °Brix, followed by molding and air drying for 1–2 hours. Granulated palm sugar was produced by further heating to approximately 96 °Brix, followed by controlled stirring to induce crystallization. The resulting crystals were ground and sieved using a 20-mesh sieve.

2.4. Analytical Method

Moisture content was determined by the gravimetric method, with samples oven-dried at 105°C until constant weight, while ash content was measured by dry ashing in a muffle furnace at 600°C [9].

The in vitro glycemic index was determined as described by [10], with modifications. Samples were subjected to enzymatic digestion using α-amylase and amyloglucosidase under simulated gastrointestinal conditions. Glucose release was measured at 0, 30, 60, 90, and 120 minutes using the DNS method at 540 nm. The area under the curve (AUC) was calculated and compared with a glucose standard to obtain the glycemic index value.

Organoleptic evaluation was conducted using a five-point hedonic scale with 15 panellists to assess colour, aroma, sweetness, and texture. Texture evaluation was adapted to each product form. Sensory data were analyzed descriptively [11]. All experiments were performed in triplicate, and results are presented as mean ± standard deviation.

3. RESULT AND DISCUSSION

3.1. Chemical Analysis

Chemical analysis of the products was conducted to determine the quality of each type of sugar produced. The results of the chemical quality tests, including moisture content and ash content, are presented in Table 1.

Table 1. Results of Chemical Analysis

Sample	Moisture Content (Mean ± SD)	Ash Content (Mean ± SD)
Liquid Sugar	32.32 ± 1.39	1.49 ± 0.07
Molded Sugar	9.77 ± 0.83	1.66 ± 0.46
Granulated Sugar	5.78 ± 1.23	1.85 ± 0.19
White Sugar	0.12 ± 0.36	0.06 ± 0.02

3.1.1. Moisture Content

Liquid palm sugar had the highest moisture content (32.32%), followed by molded palm sugar (9.77%), granulated palm sugar (5.78%), and white sugar (0.12%). Differences in moisture reflect the effect of processing and product form. Extended heating reduces moisture content, resulting in lower water content in moulded and granulated palm sugar compared to liquid palm sugar [12]. Lower moisture contributes to a drier, harder texture and improved shelf life by reducing water activity [13]. White sugar meets the SNI 10-3410-1992 standard (max 0.1%), while molded and granulated palm sugar comply with SNI 01-3743-1995 (max 10% and 3%, respectively). Liquid palm sugar lacks a specific SNI standard, so its evaluation is comparative.

3.1.2. Ash Content

Palm sugar ash content ranged from 1.49–1.85%, with molded (1.66%), granulated (1.85%), and liquid (1.49%) forms below the SNI limit of 2.5%. White sugar had 0.06%, consistent with the SNI limit of 0.2% (SNI 10-3410-1992). The higher ash content in palm sugar indicates the presence of minerals such as potassium, sodium, magnesium, calcium, and iron [14], whereas white sugar is mainly pure sucrose [15].

3.2. *In Vitro* Glycemic Index Test

Glycemic response was studied in vitro using a digestive system simulation to illustrate carbohydrate breakdown and glucose release during digestion. The increase in blood glucose levels after eating is due to the hydrolysis of carbohydrates into glucose and their absorption in the small intestine. In this Study, in vitro glycemic index was determined for liquid palm sugar, moulded palm sugar, crystallised palm sugar, and white sugar, with the glycemic responses presented in Figure 1.

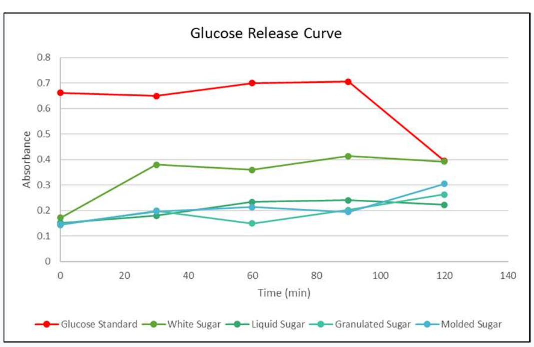

Fig 1. In vitro glycemic response to standard glucose, white sugar, liquid sugar, granulated sugar, and molded sugar.

Figure 1 shows the amount of glucose released during incubation from 0–120 minutes for both test samples and a standard glucose reference. Each type of sugar shows a different glucose release pattern at each time point. The glycemic response is determined by comparing the area under the glucose release curve (AUC) of the sample to that of standard glucose.

The glycemic index is classified into three categories: low (<55), medium (56–69), and high (≥70) [16]. Based on the calculations presented in Table 2, the three types of palm sugar have low glycemic index values: 39 for liquid palm sugar, 37 for moulded palm sugar, and 35 for granulated palm sugar. In contrast, white sugar has a glycemic index value of 60, which falls into the medium category. The glycemic response, from lowest to highest, is as follows: granulated palm sugar, molded palm sugar, liquid palm sugar, and white sugar.

The low glycemic index of palm sugar indicates that glucose is released more slowly than with white sugar. These findings align with several previous studies that report palm sugar has a lower glycemic index than refined sugar, such as white sugar, due to differences in its composition and chemical structure [17]. The lower the glycemic index of a food, the slower the increase in blood glucose levels after consumption, thus providing a more stable glycemic response [18]

This difference in glycemic response can be explained by the composition of palm sugar, which is not only dominated by sucrose but also contains fructose and maltose [19]. The presence of a mixture of these sugars can affect the rate of hydrolysis and glucose release during digestion, leading to a lower glycemic response compared to white sugar, which is almost entirely composed of pure sucrose. Additionally, palm sugar also contains minerals such as potassium and magnesium, which have been reported to play a role in modulating glucose metabolism and indirectly affecting the glycemic response [20, 21]

Overall, the in vitro glycemic index analysis shows that palm sugar, in its liquid, moulded, and crystallised forms, has a lower glycemic response than white sugar. These findings strengthen the potential of palm sugar as a natural low-glycemic alternative sweetener, making it relatively safer for helping regulate blood glucose levels compared to white sugar, particularly for individuals who need to manage their glycemic response.

3.3. Organoleptic Test

Organoleptic testing was conducted to assess panellists' preferences for the colour, aroma, sweetness, and texture of liquid, moulded, and granulated palm sugar, and white sugar (Table 3).

Table 3. Organoleptic Value of Liquid Palm Sugar, Molded Palm Sugar, Granulated Palm Sugar, and White Sugar Products

Parameters	Liquid Sugar (Mean ± SD)	Molded Sugar (Mean ± SD)	Granulated Sugar (Mean ± SD)	White Sugar (Mean ± SD)
Color	4.20 ± 0.30	3.85 ± 0.38	4.15 ± 0.32	3.70 ± 0.40
Aroma	3.90 ± 0.36	4.25 ± 0.34	4.45 ± 0.28	3.55 ± 0.42
Taste	4.30 ± 0.29	4.25 ± 0.35	4.20 ± 0.33	4.55 ± 0.24
Texture	3.95 ± 0.36	3.85 ± 0.41	4.40 ± 0.27	3.90 ± 0.38

3.3.1. Color

Panellists rated the colour of liquid and granulated palm sugar higher (4.20 and 4.15, respectively) than moulded palm sugar (3.85) and white sugar (3.70). The brown colour of palm sugar is mainly due to caramelisation and, to a lesser extent, to Maillard

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reactions during heating, producing pigments such as caramelan, caramelen, and melanoidins [22]. White sugar is visually less distinctive due to its high sucrose purity, leading to lower colour preference [23].

3.3.2. Aroma

Granulated palm sugar scored highest for aroma (4.45), followed by molded (4.25), liquid (3.90), and white sugar (3.55). Palm sugar's aroma is derived from volatile compounds formed during caramelization and Maillard reactions, including furans, aldehydes, and ketones [22, 24]. White sugar has a minimal aroma because it lacks these compounds.

3.3.3. Taste (Sweetness)

White sugar was rated sweetest (4.55), followed by liquid palm sugar (4.30), molded (4.25), and granulated (4.20). White sugar's higher perceived sweetness is due to nearly pure sucrose. In contrast, palm sugar contains sucrose, fructose, and maltose, along with minerals such as potassium and magnesium, which modulate flavour and slightly reduce perceived sweetness [19, 20]. Browning reactions during heating also contribute to the unique flavor and aftertaste.

3.3.4. Texture

Granulated palm sugar scored highest for texture (4.40) due to its granular form, which is easy to handle, measure, and dissolve. Liquid palm sugar (3.95) has a viscous texture, molded palm sugar (3.85) is solid with a slightly rough surface, and white sugar (3.90) has a neutral crystalline texture. The granular structure of granulated palm sugar offers greater convenience and was preferred by panellists.

4. CONCLUSION

Based on the results of this Study, it can be concluded that the form of palm sugar affects its chemical properties, glycemic response, and sensory acceptance. Moisture content varied among the products: liquid palm sugar at 32.32%, moulded palm sugar at 9.77%, and granulated palm sugar at 5.78%, while ash content ranged from 1.49% in liquid palm sugar to 1.85% in granulated palm sugar. All products met the relevant quality standards for palm sugar. The in vitro glycemic index (GI) values were 39 for liquid palm sugar, 37 for moulded palm sugar, and 35 for granulated palm sugar, all of which are classified as low and significantly lower than white sugar (GI = 60, medium). The low glycemic index of palm sugar is attributed to its mixed sugar composition, presence of minerals, and food matrix characteristics that slow glucose release during digestion. Sensory evaluation showed that all palm sugar products were well accepted, with granulated palm sugar receiving the highest scores for aroma and texture. These findings provide a scientific basis for developing palm sugar as a natural, low-glycemic sweetener and support the downstream development and competitiveness of Indonesian palm sugar products.

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