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Processing and Quality of Crystalized Palm Sugar in Indonesia: A Review

Hary Kuniawan[1,✉], Sri Rahayoe[2], Hanim Zuhrotul Amnah[2]

[1] Department of Agricultural Engineering, Faculty of Food Technology and Agroindustry, University of Mataram, INDONESIA.

[2] Department of Agricultural Engineering and Biosystem, Faculty Agricultural Technology, Universitas Gadjah Mada, Yogyakarta, INDONESIA

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Corresponding Author:
✉ manato.iriye.hk@gmail.com
(Hary Kurniawan)

ABSTRACT

Crystalized palm sugar derived from coconut and arenga palm sap has high-value for industrial products. The crystalized sugar offers several advantages over molded palm sugar, including a longer shelf life, lower glycemic index, and greater flexibility in its applications. However, palm sugar production in Indonesia is still predominantly carried out using traditional methods, which are inefficient in terms of quality control and production capacity. This review explores various aspects of palm sugar processing and quality in Indonesia, including raw materials, production processes, quality determinants, as well as challenges and development prospects. Key factors influencing product quality include the quality of raw materials, cooking techniques, drying methods, and proper storage practices. Uncontrolled fermentation of sap can hinder crystallization, while high moisture content may cause clumping and reduce product stability. To enhance global competitiveness, palm sugar must meet both the national and international certifications. The main challenges in this industry include the lack of Good Manufacturing Practices (GMP), limited adoption of modern processing technologies, and inconsistency in product quality. Quality improvement efforts through artisan training, production modernization, and supply chain strengthening are essential to ensuring that Indonesian palm sugar can compete in international markets. With proper strategies, palm sugar holds promising potential as a flagship export commodity from Indonesia.

1. INTRODUCTION

The production of molded palm sugar –locally named as *gula merah cetak*– from coconut, Arenga, or siwalan (lontar) sap has been practiced for generations and remains a common activity among sugar artisans in Indonesia. Currently, the production of molded sugar has shown positive development and contributes significantly to the economy of sap-producing regions, particularly those with abundant palm resources, as illustrated in (Sahat, 2017). In addition to molded sugar, artisans have also developed a derivative product known as palm sugar granules (locally called as *gula semut*), characterized by its fine granular or crystalline form. Palm sugar granules can be produced directly from fresh sap or through melting and recrystallizing molded brown sugar. Compared to the production process of conventional molded sugar, this method requires longer processing time due to additional steps such as drying and sieving to achieve a uniform particle size (Indrawati *et al*., 2020; Irawan *et al*., 2009; Pangemanan *et al*., 2019).

Palm sugar granules play a strategic role in Indonesia's food industry, serving both as a leading domestic product and a promising export commodity. The demand for this product is projected to increase by 10% to 15% annually, reflecting significant market potential at both national and international levels (Maulana, 2023). The appeal of palm sugar lies in its unique sensory and functional characteristics, including its distinctive taste and aroma, natural brown color that enhances product appearance, and high solubility in water. It is highly adaptable for use in a wide variety of food and beverage applications. Its low moisture content –typically below 3%– contributes to a longer shelf life.

Table 1. Distribution of palm sugar and coconut sugar business types across provinces in Indonesia (Sahat, 2017)

No	Province	Business Type
1	Aceh	Palm Sugar Processing
2	North Sumatra	Palm Sugar and Its Processing
3	West Sumatra	Palm Sugar
4	Riau	Coconut Sugar
5	Lampung	Palm Sugar and Its Industry
6	Jambi	Palm Sugar
7	Bengkulu	Palm Sugar, Coconut Sugar
8	South Sumatra	Palm Sugar and Its Processing
9	Bangka Belitung	Palm Sugar
10	West Kalimantan	Coconut Sugar, Palm Sugar
11	Central Kalimantan	Palm Sugar
12	South Kalimantan	Palm Sugar
13	East Kalimantan	Palm Sugar
14	Banten	Palm Sugar, Coconut Sugar, and Palm Sugar Processing
15	West Java	Palm Sugar and Its Processing, Coconut Sugar and Its Processing
16	Central Java	Palm Sugar and Its Processing, Coconut Sugar and Its Processing
17	East Java	Palm Sugar, Coconut Sugar, Palm Sugar Processing
18	Bali	Coconut Sugar
19	West Nusa Tenggara	Palm Sugar, Coconut Sugar
20	East Nusa Tenggara	Palm Sugar and Its Processing
21	West Sulawesi	Palm Sugar and Its Processing
22	Central Sulawesi	Coconut Sugar, Palm Sugar
23	South Sulawesi	Coconut Sugar, Palm Sugar
24	Southeast Sulawesi	Palm Sugar
25	Maluku	Palm Sugar
26	North Maluku	Palm Sugar
27	North Sumatra	Palm Sugar
28	West Papua	Palm Sugar
29	Papua	Palm Sugar

Furthermore, its higher market value compared to molded palm sugar offers greater economic returns for producers, while ease of packaging and distribution further enhances its competitiveness (Mela et al., 2020; Hafid *et al*., 2022; Haryanti & Mustaufik, 2011; Mustaufik *et al*., 2014). Beyond its physical and sensory advantages, palm sugar is also recognized for its relatively low glycemic index (GI), which ranges from 35 to 42 (Srikaeo & Thongta, 2015). GI is a crucial nutritional indicator used to evaluate how rapidly carbohydrate-containing foods raise blood glucose levels and is particularly relevant for dietary management among individuals with diabetes (Trinidad *et al*., 2010). Asghar *et al*. (2020) reported that coconut sap sugar contains lower levels of sucrose than cane sugar, contributing to slower glucose release and a lower glycemic response. In addition, palm sugar is rich in essential micronutrients such as potassium, magnesium, zinc, and iron, as well as vitamin C and B-complex vitamins –nutrients that are typically absent in refined sugars (Maryani *et al*., 2021). The presence of bioactive compounds such as polyphenols and antioxidants further enhances its health potential, offering additional benefits beyond glycemic control (Cory *et al*., 2018). Thus, palm sugar granules serve not only as a natural sweetener but also as a functional food ingredient with potential to support overall metabolic health.

From an economic standpoint, converting molded sugar into palm sugar granules has proven to significantly improve artisan livelihoods. Pratiwi *et al*. (2019) reported that processing molded sugar into granules increases the market value, thus improving income. Mulyadi (2011), similarly noted that this product diversification aims to raise selling prices and extend shelf life, as granulated palm sugar has better storage stability than molded sugar. However, despite its great potential, production techniques across regions in Indonesia remain relatively unchanged and continue to rely on traditional methods. Most production equipment is rudimentary, and processing remains largely manual (Irawan *et al*., 2009).

Numerous studies have been conducted on palm sugar production and its business feasibility, covering market potential, technical processes, management, and financial aspects (Mela et al., 2020; Haryanti & Mustaufik, 2011;

Mulyadi, 2011; Mustaufik *et al*., 2014; Susi, 2013). Nevertheless, comprehensive information on processing methods, quality parameters, and product stability during storage is still limited. This review therefore aims to provide a thorough examination of key aspects of the crystalized palm sugar industry, including raw material handling, processing techniques, quality-influencing factors, storage stability, and the challenges and prospects of this industry.

2. PALM SUGAR VS. CANE SUGAR

Sugarcane and palm sugar are two of the most widely used natural sweeteners in the modern food industry (Hadi & Nastiti, 2024). These sweeteners differ significantly in their physical properties, chemical composition, key constituents, and caloric value. Palm sugar, derived from the sap of palm species such as coconut, aren, siwalan, nipa, and lontar, typically has a darker color and coarser texture. In contrast, refined sugarcane sugar is white and fine in texture, making it more prevalent in processed foods and beverages (Jannah, 2017; Hadi & Nastiti, 2024). The darker color of palm sugar is attributed to its higher melanoidin content, which gives it a golden to brown hue, while refined cane sugar contains minimal melanoidin (Garusti *et al*., 2019). Moreover, palm sugar tends to have higher moisture content and is hygroscopic, making it prone to absorb moisture from the ambient and thus less stable during storage (Kurniawan, 2020).

Chemically, sugarcane is composed almost entirely of pure sucrose, whereas palm sugar contains a lower proportion of sucrose along with relatively higher levels of glucose and fructose (Choong *et al*., 2016; Maryani *et al*., 2021). This combination contributes to its more complex and distinctive sweetness (Kurniawan *et al*., 2018; Saputro *et al*., 2017). From a nutritional standpoint, palm sugar is considered superior due to its content of essential minerals such as potassium, magnesium, and zinc, which are typically absent in refined cane sugar (Choong *et al*., 2016). It also contains bioactive compounds, including antioxidants and natural dietary fiber from sap, which may support digestive health (Sarkar *et al*., 2023). In terms of sustainability, palm sugar production generally employs traditional agricultural practices that are more environmentally friendly and use fewer chemicals (Salsabila *et al*., 2024). Nevertheless, challenges remain, particularly regarding supply limitations, relatively higher prices, and inconsistent product quality due to a lack of standardization (Kurniawan *et al*., 2018). Therefore, the choice between palm sugar and cane sugar should be based on specific nutritional needs, consumer preferences, and application purposes, with palm sugar positioned as a healthier and more sustainable alternative.

3. RAW MATERIALS FOR PALM SUGAR PRODUCTION

Several species within the Arecaceae family—including coconut tree (*Cocos nucifera*), Arenga palm (*Arenga pinnata*), nipa palm (*Nypa fruticans*), palmyra palm (*Borassus flabellifer*), date palm (*Phoenix dactylifera*), and oil palm (*Elaeis guineensis*)—are known to produce sap that can be processed into molded and granulated palm sugar (Anggraini *et al*., 2025; Kurniawan *et al*., 2018). Among these, only coconut tree and Arenga palm have been widely adopted for commercial exploitation in Indonesia, serving as the primary sources for sap-based sugar production (Sebayang, 2016). In certain regions, traditional communities also extract sap from other palms such as nipa (Reni *et al*., 2018), palmyra (Nadja *et al*., 2023), and even aged oil palms (Indraningtyas *et al*., 2023). However, the utilization of these alternative species remains largely confined to small-scale operations and household consumption, thus having minimal impact on the national palm sugar industry.

Coconut and Arenga palm are extensively cultivated across Indonesia, with coconut playing a dominant role in terms of plantation scale and geographic distribution. Data from the Central Bureau of Statistics (BPS, 2023) indicate that smallholder coconut plantations occupy approximately 3.296 million hectares, while the Kontan Data Center (2025) reports a total plantation area of around 3.34 million hectares. These plantations are concentrated in provinces such as Riau, Central Java, and North Sulawesi, which also serve as key production hubs for coconut sap used in palm sugar processing. In contrast, sugar palm is cultivated on a smaller scale, although its coverage is gradually expanding. According to Majalah Hortus (2025), the total cultivated area of *Arenga pinnata* has reached 61,924 hectares across 26 provinces, reflecting an increase from 60,482 hectares five years earlier. Major sugar palm-producing regions include South Sulawesi, North Sumatra, and West Nusa Tenggara –areas traditionally recognized for their high-quality sap. Given its expanding cultivation and favorable agronomic traits, *Arenga pinnata* holds significant promise as a complementary resource for enhancing the sustainability and diversity of Indonesia’s palm sugar industry.

One of the most economically valuable components of coconut and Arenga trees is their sap –a sweet liquid extracted from the flower stalks. This fresh sap is characterized by a naturally sweet taste, distinctive aroma, and a color ranging from clear to slightly cloudy white. Both coconut and Arenga sap exhibit similar acidity levels, with a typical pH ranging from 6 to 7 (Iskandar & Darusalam, 2020; Xia *et al*., 2011). Their chemical compositions have been thoroughly analyzed, with comparative profiles presented by Asghar *et al*. (2020), as shown in Table 2. The methods used to extract this sap, commonly referred to as sap tapping, are generally divided into two main approaches: traditional and modern techniques. Each method has distinct characteristics in terms of tools employed, sap collection efficiency, and productivity levels. Traditional sap tapping is typically performed manually using simple instruments such as knives or machetes to make incisions on the male flower stalks (inflorescence). This process is usually carried out early in the morning, between 6:00 and 10:00 a.m., when the sap flow is at its peak (Indraningtyas *et al*., 2023). The exuding sap is collected in natural containers, such as bamboo tubes or coconut shells, affixed just below the incision point. The collected sap is generally processed immediately into various derivative products, most notably palm sugar granules. The yield obtained through this method typically ranges from 4 to 10 liters per tree per day, depending on species, plant age, and environmental conditions (Marwah *et al*., 2020).

Table 2. Chemical composition and physical properties of coconut and arenga sap (Asghar *et al*., 2020)

Attribute	Unit	Coconut Sap	Arenga Sap
Moisture content	%	85.93 ± 0.66	85.77 ± 1.17
Ash content	%	0.27 ± 0.03	0.25 ± 0.02
Crude Fat	%	0.01 ± 0.00	0.03 ± 0.00
Protein	%	0.26 ± 0.02	0.27 ± 0.02
Carbohydrates	%	13.53 ± 0.64	14.68 ± 1.13
pH	--	5.52 ± 0.08	4.92 ± 0.07
Total suspended solid (TSS)	%	12.40 ± 1.14	13.00 ± 1.58
Color			
L*	--	38.16 ± 0.63	32.52 ± 0.75
a*	--	-0.92 ± 0.10	-0.80 ± 0.08
b*	--	-3.5 ± 0.04	-4.29 ± 0.17
C*	--	3.62 ± 0.07	4.37 ± 0.16
H*	--	1.31 ± 0.02	1.38 ± 0.02
Browning index	--	-10.21 ± 0.29	-13.71 ± 0.56

In recent years, modern tapping techniques have been increasingly adopted to improve operational efficiency, hygiene, and production consistency. Mechanized and semi-automated equipment allows for more precise incisions and higher tapping frequency. Additionally, closed sap collection systems help minimize microbial contamination. Innovations also include the integration of digital monitoring technologies –such as volume sensors and mobile applications– which enable farmers to optimize tapping schedules and management (Juni *et al*., 2024; Sawidin *et al*., 2023). These improvements not only increase sap yield but also enhance the standardization of raw material quality, which is critical for industrial-scale palm sugar processing.

Under modern methods, daily sap yield ranges from 10 to 33.57 L/tree, depending on the species and agronomic conditions (Tenda & Makarti, 2016). Considering that approximately 10 L of sap are required to produce one kilogram of palm sugar granules, this translates into promising economic opportunities for farmers. The implementation of process optimization and product diversification strategies has been shown to further increase the added value of sap, as evidenced by various community-based development programs (Lalisang, 2018; Sylvana *et al*., 2023).

Post-tapping, the initial handling of sap is critical before it is processed into palm sugar. This stage includes filtration to remove impurities and microorganisms, and the prevention of fermentation (Mahulette *et al*., 2020). Both coconut and arenga sap are highly prone to fermentation due to their sugar content, which provides an ideal medium for microbial growth (Iskandar & Darusalam, 2020). Hebbar *et al*. (2015) reported that fermentation can begin within 2 to 3 hours after sap collection. Consequently, several preservation techniques have been developed to slow down fermentation and maintain sap quality. These include ultraviolet (UV) irradiation (Imron *et al*., 2015; Kurniawan *et al*., 2020), cooling

(Hebbar *et al*., 2015; Karouw & Lay, 2018), heating (Jaya, 2015; Karouw & Lay, 2006) and pasteurization (Mulyawanti *et al*., 2012). Natural preservatives such as mangosteen latex, mara tree leaves, *cangel* bark (Lay & Karouw, 2008), *same* fruit (*Macaranga spesiosa*), coconut husks, cinnamon bark, *safat* fruit (Barlina *et al*., 2006), mangosteen peel and leaves, jackfruit bark, and *rupih* tree bark (Hamzah & Hasbullah, 1997), have also been explored. Chemical methods using sodium metabisulfite and lime (Lay & Karouw, 2008) and preservation with liquid smoke (Rusbana, 2009), are alternative options for maintaining sap quality. Because sap is highly perishable, it is usually cooked immediately after tapping if it is to be processed into molded or granulated palm sugar.

The quality of sap directly determines the quality of the resulting sugar. Environmental factors such as temperature, humidity, and tapping time significantly affect sap quality. Tapping conducted at optimal times, such as in the morning or evening, influences the sucrose content of the sap. Morning spas typically have a lower pH and sucrose level than evening sap due to higher daytime evaporation (Rachman, 2009; Wilberta *et al*., 2021). Research indicates that evening tapping tends to yield sap with a higher sucrose concentration (Adisetya *et al*., 2022). Proper tapping techniques, including hygienic methods and appropriate tools, are critical for ensuring sap quality and preventing contamination (Sawidin *et al*., 2023). For high-quality palm sugar production, the sap should have a pH between 6 and 7 and be free of impurities to facilitate crystallization (Fadilla, 2021; Susi, 2013). Fermented sap contains higher levels of reducing sugars, which can inhibit crystallization and make palm sugar granules difficult to form (Baharuddin *et al*., 2007; Pratama *et al*., 2015). Meanwhile, molded sugar solution used as raw material for palm sugar production typically has a pH range of 6.10 to 8.40, which also affects crystallization success (Zuliana *et al*., 2016).

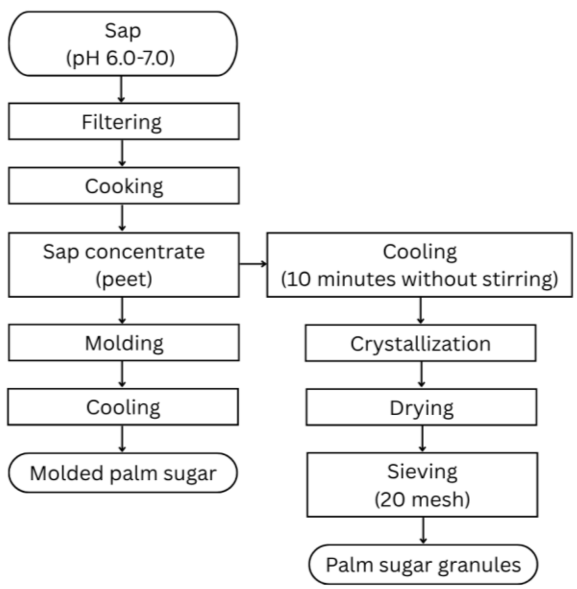

Figure 1. Processing flow diagram of molded and granulated palm sugar (Nawansih *et al*., 2017; Rachman, 2009)

4. PALM SUGAR PRODUCTION PROCESS

The main raw materials for palm sugar granules are either fresh sap (from coconut or arenga) or reprocessed molded sugar. Figure 1 illustrates the stages of both molded and granulated palm sugar production. Using fresh sap poses certain challenges due to its perishable nature, which requires immediate cooking after tapping to prevent fermentation and quality deterioration (Mulyadi, 2011). If fermentation occurs, the sap becomes cloudy, yellowish, and acidic in taste, and the resulting sugar fails to crystallize properly (Pratama *et al*., 2015). The reprocessing of molded palm sugar through the stages of dissolution, filtration, and recrystallization has become an increasingly common practice in the sugar industry to address growing market demand for high-quality products. The process begins by dissolving pieces of molded sugar in hot water to break down solid masses and eliminate physical contaminants. Once a homogeneous solution is achieved, filtration is carried out to remove any remaining insoluble impurities. The clear solution is then recooked and cooled under controlled conditions to allow the formation of purer and more uniform sugar crystals with improved visual appeal. This is followed by drying until the final product is sugar with lower moisture content, finer texture, enhanced cleanliness, and extended shelf life (Handayani *et al*., 2022; Musita, 2019). Various production methods from both fresh sap and molded sugar have been reported in the literature (Mela et al., 2020; Pangemanan *et al*., 2019; Zuliana *et al*., 2016; Pratiwi *et al*., 2019).

Palm sugar granules can be produced using two main methods: traditional (Mela et al., 2020; Pangemanan *et al*., 2019) and mechanical (Pardede, 2018; Sulastri *et al*., 2018). In the traditional method, fresh sap or molded sugar solution is first filtered to remove dirt and residue, then cooked in large woks over wood-fired stoves until thickened. This cooking process typically takes 4–6 hours, depending on the volume of sap or sugar solution used (Lay & Heliyanto, 2011). While cooking, foam may form and disrupt crystallization. To reduce foaming, artisans often add coconut oil (Mustaufik *et al*., 2014), grated candlenuts (Marsigit, 2005) or grated coconut (Pangemanan *et al*., 2019). Manual stirring continues throughout cooking until crystallization begins, as shown in Figure 2a.

(a) (b)

Figure 2. Stirring process during palm sugar granulation: (a) manual stirring; (b) mechanical stirring

The endpoint of cooking is a critical factor in determining the success of palm sugar crystallization. If cooking stops too early, crystallization may not occur, or the sugar may clump. On the other hand, prolonged cooking beyond the optimal point leads to excessive caramelization or even burning. Artisans typically use two simple tests to identify the endpoint: (1) a drop of thick syrup is placed into cold water; if it solidifies without dissolving, the syrup is ready; (2) syrup is dripped or lifted with a spoon, and if it forms threads, cooking is complete.

The next stage is crystallization (granulation), during which the thickened syrup is cooled and stirred continuously until crystals form. The semi-dry granules are then oven-dried to reach the desired moisture level. Once dried, the granules are sieved using mesh 15 or 20 to ensure uniform particle size before being packaged for distribution (Mela et al., 2020; Mustaufik *et al*., 2014; Pratama *et al*., 2015).

The conventional method offers advantages such as low equipment cost due to the use of simple tools –often doubling as household kitchen equipment (Azizah *et al*., 2019; Mardinawati *et al*., 2019; Wahyuni *et al*., 2020). However, it also has limitations, including low production capacity, longer processing times, and inconsistent product quality. The moisture content of sugar produced through traditional methods tends to be higher, which shortens shelf life and increases the risk of clumping. Hygiene is also difficult to control due to manual operations. Furthermore, the use of firewood leads to unstable heating, increasing the risk of burning the sugar and reducing overall product quality (Pangemanan *et al*., 2019).

To improve efficiency, many artisans are transitioning to mechanical methods. In this approach, sap or sugar solution is cooked in a large pan over a gas burner and stirred using a motorized mechanical stirrer, as shown in Figure 2b (Sulastri *et al*., 2018). Mechanical systems have been developed in various forms, including semi-horizontal drums with motor-driven stirrers and steam boilers as heat sources (Kurniawan, 2011). Yunanto (2012) designed a 5 kg-capacity crystallizer using centrifugal force and blade rotation to produce granules from reprocessed molded sugar (Figure 3a). Similarly, Pardede (2018) developed a 5 kg/hour capacity stirrer using an open pan and a 1 HP motor-driven mixer

(Figure 3b). Indrawati *et al*. (2020) designed a stainless-steel machine (600 × 500 × 1000 mm) with a 20-liter capacity and a 0.5 HP motor for hygienic production (Figure 3c). This system uses LPG burners, hoses, and regulators to enhance heating efficiency.

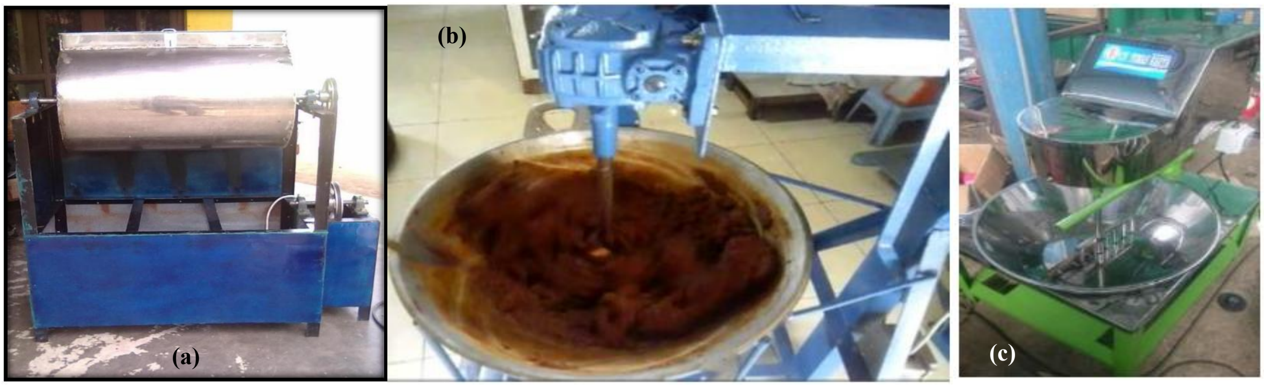

Figure 3. Different machine to crystallize palm sugar: (a) Tubular-type palm sugar (Yunanto, 2012); (b) Open-pan palm sugar stirrer (Pardede, 2018); (c) Sap cooking machine (Indrawati *et al*., 2020).

Mechanical methods offer several advantages, including faster cooking, improved hygiene, higher production capacity, and consistent product quality. Nevertheless, they require higher capital investment and operational costs, especially due to the use of gas, which some artisans consider more expensive than firewood. Despite this, improved efficiency and product quality make mechanical processing more economically viable in the long run.

In both conventional and mechanical systems, stirring plays a critical role in evaporation and crystallization (Dewi *et al*., 2014). Manual stirring is typically done using spatulas, and some artisans use coconut shells to break larger clumps into smaller granules (Azizah *et al*., 2019; Mardinawati *et al*., 2019). This process requires significant effort, especially since stirring must continue until the desired consistency is reached. In mechanical methods, stirring is automated from start to finish, driven by electric motors, allowing for more efficient and consistent crystallization. Thus, the design and configuration of stirring mechanisms are crucial for improving production efficiency, uniform crystal size, and overall product quality (Sulastri *et al*., 2018).

5. QUALITY DETERMINANTS OF PALM SUGAR GRANULES

The quality of palm sugar granules is influenced by various factors, including raw material characteristics, production techniques, and the physicochemical parameters that define product standards. According to (Susi, 2013) one of the main issues in the palm sugar industry is the high variability and inconsistency in product quality among producers, which often results in products failing to meet the Indonesian National Standard SNI 01-3743-2021 (BSN, 2021). One of the primary causes of this inconsistency is the variation in raw material quality, whether from fresh sap or reprocessed molded sugar.

Fermented sap is unsuitable for palm sugar production because it inhibits crystallization and leads to inferior product quality (Lay & Karouw, 2008). Similarly, the quality of molded sugar used as a base material plays a significant role in determining the final product's quality (Pratiwi *et al*., 2019). Molded sugar from different producers may vary in quality, directly affecting the consistency of the granulated product (Zuliana *et al*., 2016). In general, poor-quality sap yields low-grade molded sugar, which in turn produces low-quality palm sugar granules. Therefore, selecting high-quality raw materials is crucial to ensure that the final product meets established standards (Susi, 2013).

Color is one of the most important quality attributes, as it affects consumer appeal and acceptance (Dewi *et al*., 2014; Kurniawan, 2020). One common issue is inconsistency in color, which can range from light brown to dark brown. Products that are too dark may be perceived as less attractive by consumers. This variation is primarily caused by uncontrolled browning reactions during processing, especially at high temperatures and prolonged cooking times (Dewi *et al*., 2014; Putra, 2016). According to the SNI standard, palm sugar granules should have a color ranging from yellowish-brown to brown, with a normal taste and distinctive aroma (Lay & Karouw, 2008). Sodium metabisulfite has been reported to help control excessive browning (Putra, 2016). The brown color in palm sugar results mainly from Maillard reactions and caramelization, both of which produce melanoidin pigments (Dewi *et al*., 2014; Putra, 2016). The Maillard reaction is a non-enzymatic browning process involving reducing sugars and amino acids during heating (Carabasa-Giribet & Ibarz-Ribas, 2000), while caramelization is the thermal degradation of sugar that creates a characteristic brown color and flavor (Kocadağli & Gökmen, 2018). As the cooking temperature increases, the color intensity and flavor of the product change significantly (Dewi *et al*., 2014). Therefore, controlling the time and temperature during cooking is critical to maintaining the desired sensory qualities of the final product.

Besides color, particle size is another important quality parameter that affects market acceptance. Karouw & Lay (2006) and Lay & Karouw (2008) reported that palm sugar granules produced by small-scale farmers often have irregular particle sizes, ranging from fine crystals to large chunks. To achieve uniformity, sieving is an essential step in the production process. Although the SNI standard does not specify particle size, studies have shown that sieving through mesh sizes 18 or 20 produces granules with better consistency and market compliance (Lay & Heliyanto, 2011; Lay & Karouw, 2008). Hence, particle size control through sieving contributes to improved product quality and competitiveness.

Moisture content is another critical determinant of 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 SNI standard (Kurniawan *et al*., 2020; Susi, 2013). High moisture content results in coarser crystals and a more humid texture, which shortens shelf life and increases the risk of clumping during storage (Kurniawan *et al*., 2018). Moisture content is influenced by several factors, one of which is the endpoint of cooking. If cooking is stopped too early, insufficient water evaporation leads to higher moisture levels in the final product (Susi, 2013). The addition of supplementary ingredients during processing may also introduce impurities that increase the product's hygroscopicity, making it more prone to absorbing moisture from the environment. Another important factor is the drying process, where the presence or absence of this step plays a decisive role in determining final moisture levels.

Efforts to reduce moisture content include sun drying and mechanical drying. Sun drying is the simplest and most cost-effective method, but it presents hygiene challenges due to exposure to uncontrolled environmental conditions (Amanah *et al*., 2013). To address this, mechanical drying equipment has been introduced to improve product quality and processing efficiency. Amanah *et al*. (2013) reported that cabinet dryers with capacities of 5–15 kg produced optimal results at 80°C, with the best efficiency achieved at 15 kg per cycle. Kurniawan, *et al*. (2020) found that a cylindrical rack-type dryer could reduce moisture content from 5.40 to 3.02% within 3 h at 60°C. Zuliana *et al*. (2016) also reported moisture levels ranging from 1.37 to 2.43% in palm sugar dried using mechanical methods –lower than those obtained through traditional processes. Meldayanoor *et al*. (2019) showed that oven drying at 100°C for one hour yielded palm sugar with 2.97% moisture content, considered optimal for consumer preference.

6. STORAGE AND STABILITY OF PALM SUGAR GRANULES

Packaging and storage conditions play a crucial role in maintaining the quality of palm sugar granules after production. Even when hygienically processed, improper packaging and suboptimal storage environments can lead to quality degradation (Lay & Karouw, 2008). One notable characteristic of palm sugar granules is their hygroscopicity, the ability to absorb moisture from the surrounding environment. When stored under high humidity, moisture uptake can cause clumping, alter texture, and significantly reduce shelf life (Dewi, 2018; Ritonga *et al*., 2020).

Numerous studies have investigated the stability and shelf life of palm sugar under various packaging types and environmental conditions (Kurniawan *et al*., 2018; Ritonga *et al*., 2020). Lay & Karouw (2008) assessed the predicted shelf life of palm sugar stored in three types of packaging –polypropylene, polyethylene, and aluminum foil– under three different temperatures (30°C, 40°C, and 50°C) with 70% relative humidity (RH). Their results showed that at 30°C, the shelf life was 270 days (polypropylene), 133 days (polyethylene), and 1,878 days (aluminum foil). At 40°C, shelf life decreased to 154 days, 111 days, and 1,536 days, respectively. At 50°C, it dropped further to 92 days (polypropylene), 94 days (polyethylene), and 1,271 days (aluminum foil).

Similarly, Kurniawan *et al*. (2018) demonstrated that storage temperature and humidity greatly influence product stability. In their study, palm sugar stored in polyethylene packaging was tested under various temperatures (15°C, 25°C, 30°C, and 35°C) and RH conditions (77% and 98%). The longest shelf life (160 days), was observed at 15°C and 77% RH, while the shortest (only 26 days) was at 35°C and 98% RH. Ritonga *et al*. (2020) compared polyethylene and aluminum foil packaging and found that aluminum foil preserved quality for up to 18 months, whereas polyethylene packaging only extended shelf life to 11 months. In general, higher temperature and humidity accelerate deterioration, making aluminum foil the most effective packaging material for long-term storage.

In addition to moisture content changes, color alteration is another concern during storage, especially under high temperature and humidity (Dewi, 2018; Kurniawan, 2020). Kurniawan, (2020) reported that increased moisture content in palm sugar significantly affects its CIELab color parameters, including *L** (lightness), *a** (red-green), and *b** (yellow-blue) values. As moisture content rises, *L** values decrease, indicating darker product color, particularly toward dark brown, as shown in Figure . Dewi, (2018) also found that browning reactions during storage were accelerated by elevated humidity and temperature. These findings are consistent with Adawiyah *et al*. (2005), who stated that higher storage temperatures and humidity promote the Maillard and caramelization reactions responsible for brown color formation.

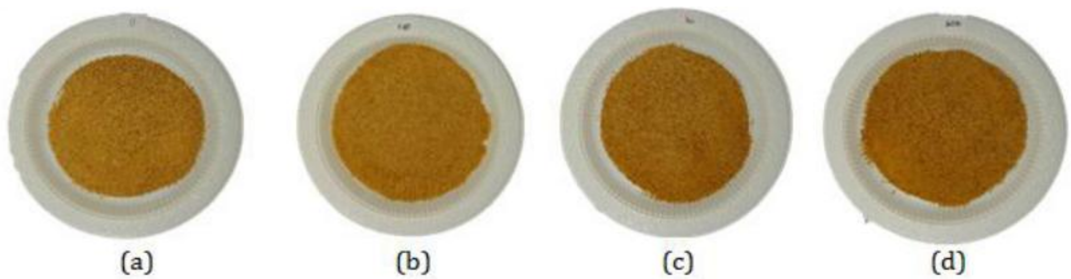

Figure 4. Palm sugar color at different moisture contents: (a) 3.87%, (b) 6.87%, (c) 7.20%, (d) 8.40% (Kurniawan, 2020)

7. CHALLENGES AND DEVELOPMENT PROSPECTS

The development of agro-industry aims to create added value, increase farmers' income, extend product shelf life, and reduce postharvest losses. Additionally, it contributes to product competitiveness, job creation, and the preservation of nutritional value by transforming raw commodities into higher-value products that appeal to consumers (Millaty, 2018; Putri, 2016). Palm sugar granules represent a promising agro-industrial sector commonly produced at the household level, particularly in rural areas. Most production is carried out individually at home using small-scale operations (Purba, 2021). Despite these limitations, the palm sugar industry holds substantial development potential, not only as a source of household income but also for stimulating regional economic growth and generating employment opportunities. Beyond domestic markets, palm sugar also has strong export prospects, driven by growing global demand for natural, healthy, and value-added food products (Arumsari & Syamsiar, 2011; Evalia, 2015; Millaty, 2018). With the right development strategies—including improvements in production technology, quality certification, and international marketing and distribution networks—palm sugar can become a leading agro-industrial export commodity for Indonesia.

Palm sugar is recognized as a strategic national commodity with significant development potential. In recent years, demand has steadily increased in both domestic and international markets, aligned with a global shift toward natural and healthy food consumption (Sahat, 2017). As a product deeply rooted in the social, economic, and cultural life of rural communities, palm sugar is highly competitive in the market due to its distinctive taste, texture, and ease of application in various food and beverage industries.

Evalia (2015) reported that the largest domestic demand for palm sugar comes from the food and pharmaceutical industries, where it is used as a key ingredient or natural sweetener in food formulations. Internationally, demand is rising in countries with high consumption of health-oriented products, such as Saudi Arabia, Australia, Singapore, Malaysia, Hong Kong, South Korea, Japan, and several European countries including Germany and Switzerland. According to (Sahat, 2017), Northwestern European countries are the largest consumers and importers of palm sugar worldwide. This trend highlights the strong export potential of palm sugar and the opportunity for Indonesia to expand its presence in global markets. To enhance competitiveness and export capacity, key strategies include increasing production capacity, complying with international standards, and optimizing global distribution and marketing channels.

According to Warta Ekspor (Sahat, 2017), global trade statistics indicate an upward trend in the international palm sugar market, as illustrated in Figure . Between 2012 and 2016, palm sugar imports grew at an average annual rate of 1.92%, while exports exhibited a higher average annual growth of 6%. Based on the 2024 report from the Center for Data and Information Systems of the Ministry of Trade, the export value of coconut sugar reached USD 10.58 million in 2023, representing a dramatic increase of 448.41% compared to 2022. This surge reflects the increasing competitiveness of Indonesian palm sugar in the international market and its strategic importance in the country's agro-industrial export portfolio. Significant export activity has also been recorded in Banyumas Regency, one of Indonesia's major coconut sugar-producing regions. In May 2025, a total of 18.5 metric tons of granulated palm sugar was successfully exported to Hungary by BUMDes Kabul Ciptaku of Langgongsari Village, Cilongok District. The trade was valued at approximately USD 30,000–35,000, highlighting both the international demand for palm sugar and the growing role of rural enterprises in global value chains (Suratdunia.com, 2025; Antaranews.com, 2025). Notably, Banyumas contributes nearly 80% of Indonesia's total granulated palm sugar production, while Indonesia itself supplies about 90% of global demand. Although comprehensive global production data is limited, Asia is believed to be the largest producing region, with Indonesia, India, and Cambodia playing key roles. Indonesia is currently considered the world's largest palm sugar producer (Sahat, 2017). With increasing international demand, Indonesia has a significant opportunity to strengthen production capacity, diversify products, and optimize exports to maintain its leadership in the global palm sugar market.

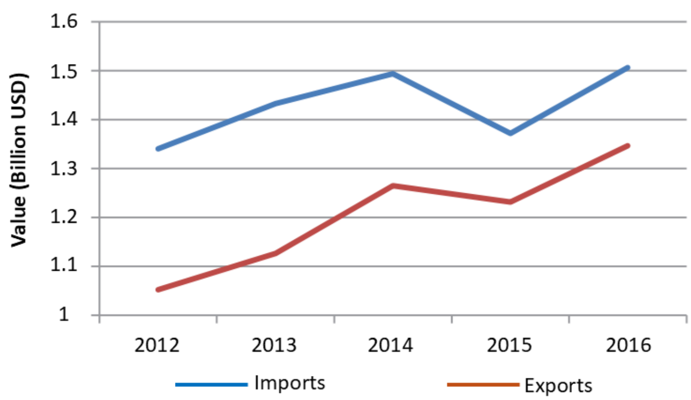

Figure 5. Global palm sugar import and export value (Sahat, 2017)

Despite its promising market potential, the Indonesian palm sugar industry still faces several challenges. These include: (1) production facilities that do not yet comply with Good Manufacturing Practices (GMP); (2) limited awareness among small producers regarding the importance of product quality; (3) inconsistency in quality control implementation; (4) poor understanding of quality standards across actors in the value chain; (5) lack of knowledge about optimal cultivation practices to improve sap quality and yield; and (6) the use of traditional technologies that hinder improvements in efficiency and quality (Hikmah *et al*., 2022; Imran *et al*., 2023; Maulana *et al*., 2023; Sugiharto *et al*., 2023). Lay & Heliyanto (2011) emphasized that the development of palm sugar agro-industry depends on several key factors, including farmer empowerment, processing technology, financial investment, product development, and marketing strategy. Evalia (2015) also noted that development is hindered by limited information on appropriate technologies, unstable product quality and volume, low human resource capacity, restricted market access, and the absence of clear quality standards for export. The continued reliance on traditional processing methods remains a major constraint on product competitiveness in international markets. Addressing these challenges will require structured industrial development strategies, including technological modernization, international certification, supply chain reinforcement, and capacity building through training and education. These initiatives will support the competitiveness of Indonesia's palm sugar industry in both domestic and global markets.

The adoption of innovative technologies in small and medium-scale palm sugar processing is increasing in response to the need for improved productivity, processing efficiency, and product quality that meets consumer expectations (Lay & Heliyanto, 2011). Although technological innovation has great potential to drive industry development, its implementation among small producers faces several obstacles. Successful technology integration requires supporting equipment, technical training, and effective market regulation, particularly through government and institutional support. One example of modernization is the introduction of palm sugar processing equipment to small producers. In the "Maju Bersama" small and medium enterprises (SME) in Kekait Village, Gunungsari District, West Nusa Tenggara, technology introduction programs have been implemented to improve production capacity (Widyasari *et al*., 2019). This program included demonstrations of production machines designed to enhance process effectiveness, product quality, and reduce dependency on traditional methods, as illustrated in

Figure . The application of modern technology is expected to bring positive impacts in terms of product quality, production efficiency, and competitiveness in both domestic and international markets. Collaboration among government, academia, and industry players is essential to support technology adoption and accelerate the transformation of Indonesia's palm sugar sector.

Figure 6. Training on mechanical palm sugar production (Widyasari *et al*., 2019).

Human resource development efforts are also critical, particularly in improving the ability of producers to generate products that comply with GMP standards (Azizah *et al*., 2019; Fadilla, 2021). Although Evalia (2015) noted that appropriate technology adoption is the top priority, a major challenge remains the lack of producer awareness and knowledge about product quality standards. Inconsistency in applying quality standards continues to be a key barrier, with many palm sugar products still falling short of export requirements. A strategic approach is needed to promote and implement national and international product standards. One such standard is SII 0268-85, which defines the composition and quality specifications for palm sugar, as shown in Table 3. In the global market, organic palm sugar has high demand, with stricter quality criteria listed in Table 2. To compete globally, producers must obtain organic certification from internationally recognized institutions, including the European Union Regulation, USDA National Organic Program, Japanese Agricultural Standards (JAS), and Control Union Certification (CUC).

To strengthen its competitiveness in export markets, palm sugar must be positioned as a unique product that reflects Indonesia's tropical biodiversity and rural heritage. In addition to meeting international certification and quality standards, effective differentiation strategies should emphasize the origin, sustainability, and socio-economic impact of the product—such as empowering local farmers and supporting small enterprises. This approach not only adds economic value to local industries but also enhances Indonesia's reputation as a leading producer of premium, natural palm sugar in global markets (Sahat, 2017). With proper branding, certification, and marketing strategies, Indonesian palm sugar has a strong opportunity to thrive as a competitive export commodity.

Table 1. Composition and quality standards for coconut sugar referenced by exporters to various destination countries (SII 0268-85)

No.	Component	Requirement
1	Total Sugar (Sucrose and Reducing Sugar)	Minimal 80
2	Sucrose (%)	Minimal 75
3	Reducing Sugar (%)	Maksimal 6
4	Moisture (%)	Maksimal 3
5	Ash (%)	Maksimal 2
6	Water-Insoluble Solids	Maksimal 1
7	Coloring Agents	Yang Diijinkan
8	Hazardous Metals (Cu, Hg, Pb, As)	Negatif
9	Starch	Negatif
10	Form	Kristal/Serbuk

Source: Directorate of Domestic Trade and SME Products, Ministry of Trade

Table 2. Requirements for organic palm sugar

No.	Requirement
1	Free from chemicals (pesticides, herbicides, etc.), preservatives, and dyes
2	100% pure sap from coconut or arenga palms
3	Particle fineness of 18 mesh
4	Maximum moisture content of 1.5%
5	Free from contaminants such as stones, paper, plastic, or burnt sap

Source: Directorate of Domestic Trade and SME Products, Ministry of Trade

7. CONCLUSION

Palm sugar granules hold significant potential in the food industry as a high-value agro-industrial product. Their superior shelf life and low glycemic index make them an increasingly attractive option in both domestic and international markets. However, the main challenges facing the palm sugar industry include inconsistent product quality, outdated processing technology, and the lack of standardized quality compliance for export. To address these issues, it is crucial to enhance artisan capacity through technological training and the implementation of Good Manufacturing Practices (GMP). Strengthening the supply chain is also essential to ensure that Indonesian palm sugar can compete globally. The adoption of efficient processing technologies and a focus on export market development are key strategies to improve the competitiveness of Indonesian palm sugar in the future.

Palm sugar is produced from coconut or Arenga sap through a crystallization process, resulting in a granular product with several advantages over traditional molded sugar. These include a longer shelf life, versatile usage, and a lower glycemic index compared to refined sugar. In Indonesia, palm sugar production is still dominated by traditional methods, which, while economical, often result in inconsistent quality and limited production capacity. In contrast, mechanical processing offers greater efficiency and product uniformity, albeit requiring higher initial investment. Product quality is heavily influenced by the quality of sap, cooking techniques, drying methods, and storage conditions. Uncontrolled fermentation can degrade sap quality, while excessive moisture content contributes to clumping and reduced shelf life. Therefore, the application of modern processing technology and proper packaging plays a vital role in maintaining product stability.

To improve global market competitiveness, palm sugar must comply with both national standards SNI 01-3743-2021 (BSN, 2021) and international certifications such as USDA Organic and EU Organic. The primary obstacles in the Indonesian palm sugar industry include variability in product quality, limited technological advancement among small and medium enterprises, and increasingly stringent export requirements. Strategic efforts to enhance product quality—

through artisan training, the adoption of innovative technologies, and the application of GMP—are essential for industry development. Strengthening the supply chain through collaboration among farmers, producers, and government stakeholders, along with product diversification, will be key in establishing palm sugar as a flagship commodity capable of competing in the global market.

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