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Production of Healthy Sugar by Adding Winter Melon [*Benincasa hispida* (Thunb.) Cogn.] Using Coconut Sap

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ABSTRACT: The increasing prevalence of health issues such as diabetes, obesity, and hypertension due to excessive sugar consumption has prompted the need for healthier sugar alternatives. This study examines the physical characteristics of sugar produced from coconut sap with the addition of winter melon extract using the vacuum evaporation method at controlled temperatures (50–80°C) to maintain quality and prevent excessive caramelization, resulting in a dark brown color. The results show that coconut sap has a complex sugar composition, dominated by oligosaccharides that inhibit the crystallization process, thus requiring further optimization. The addition of winter melon extract and sugar seed proved to increase the product yield by up to 10.48%, with the addition of extract causing a decrease in product brightness, but this can be overcome by adding sugar seed. The best combination was found with the addition of 10 mL of winter melon extract and 10% sugar seed. These findings confirm the potential of coconut sugar with added winter melon extract as a functional food product worth further development.

Keywords: Coconut sap; Sugar; Winter melon

1. Introduction

The rising threat of diseases such as diabetes, obesity, hypertension, and heart disease has become a major concern due to the high sugar intake in foods, beverages, and confectioneries (Chattopadhyay et al., 2014). According to the World Health Organization (WHO, 2023), approximately 442 million people globally live with diabetes, which accounts for 43% of deaths among individuals under the age of 70 and roughly 3% of total global deaths. This data highlights the urgent need to modify dietary habits, particularly in reducing excessive sugar consumption (Asghar et al., 2021). To address this issue, the food industry has increased the production of low-sugar, sugar-free, and healthier alternative sweeteners. One of the most popular alternatives is coconut sugar, known as a natural sweetener with a distinctive caramel flavor and an appealing natural brown color (Mahargiani & Subawa, 2010). The popularity of coconut sugar as a natural sweetener is also supported by its unique sensory profile and potential health benefits compared to cane sugar.

In this study, coconut sap will be used as the main ingredient, and winter melon extract (*Benincasa Hispida*) will be added to enhance its nutritional value (Al-Snafi, 2013). The winter melon fruit is known to have anti-diabetic properties and contains bioactive compounds, such as gallic acid that are believed to help regulate blood sugar levels (Fatariah et al., 2014). Next, sugar seed will be added as a starter to produce uniform crystals (Halomoan et al., 2024). However, it should be emphasized that this research does not directly analyze the content of these bioactive compounds in the final product. The focus of this research is to evaluate the effect of adding winter melon extract and sugar seeds on the physical characteristics of coconut sugar products, such as color and crystal shape produced.

The vacuum evaporation method will be used to minimize nutrient loss in the product and prevent excessive caramelization to maintain the final product's quality. This research aims to develop coconut sugar with the addition of winter melon extract, making it a healthier alternative sweetener for consumers (Kusumawaty et al., 2012).

2. Materials and Methods

2.1 Materials

The materials in this study included coconut sap as the base ingredient, winter melon (Benincasa hispida) extract for added nutritional properties, sugar seed as a starter to produce crystals. Additionally, the following equipment was used vacuum evaporator, food processor (Philips Extractor:

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HR2508), and food dehydrator will be used to remove excess water content in the final product.

2.2. Methods

The methods in this study consist of several production procedures and analysis test procedures.

2.2.1 Winter Melon Extraction

Winter melon was processed using food processor (Philips Extractor: HR2508) after being peeled and washed. Then, the extract from winter melon is concentrated to 30°Brix.

2.2.2 Sugar Production

1000 ml of coconut sap is placed into an evaporation flask and evaporated at 80°C, 250 rpm, with vacuum pump pressure set to -900 mbar (Asghar, Yusof, Mokhtar, Yaacob, et al., 2020). Winter melon extract is added in 10 ml increments when the coconut sap reaches 60°Brix. Stirring continues until the mixture reaches 74°Brix, followed by the addition of sugar seed, and the process continues until sugar is formed.

2.2.3 pH

The pH of the coconut sap was measured using a pH meter at room temperature (25 ± 1°C). Calibration was performed using pH 4.0 and pH 7.0 buffer solutions (Asghar, Yusof, Mokhtar, Yaacob, et al., 2020).

2.2.4 °Brix Analysis

°Brix was measured using a refractometer. One to two drops of the sample were placed onto the glass prism, and the °Brix value was recorded at room temperature (25 ± 1°C) (Iman et al., 2018).

2.2.5 Color Analysis

Colorimetric measurements were performed using an FRU portable colorimeter based on the CIE Lab* color space system. To analyze a sample, the FRU colorimeter was first calibrated using the provided white standard plate. The sample surface was then cleaned and positioned on a stable, flat area to ensure consistent contact. The measurement port of the device was placed firmly against the sample, avoiding external light interference. A single press of the test button initiated the reading, and the color parameters (L*, a*, b*) were automatically displayed and recorded for analysis (Hebbar et al., 2022).

2.2.6 Sugar Profile

The sugar profiling was performed using High-Performance Liquid Chromatography (HPLC) with HyperREZ column manufactured by Thermo Fisher Scientific. Coconut sap was diluted tenfold with deionized water and filtered through a 0.45 µm nylon filter. A 20-microliter sample was injected into a single-bond NH2 column (250 mm × 4.6 mm, 5 µm particle size). The column temperature was maintained at 40°C, and sugar separation was carried out isostatically at a flow rate of 1.5 ml/min. A standard curve was prepared using sugar reference standards (fructose, glucose, and sucrose) by plotting peak area against varying concentrations of each sugar (0%–5% b/v) (Asghar, Yusof, Mokhtar, Noriznan, et al., 2020).

3. Results and Discussion

3.1 Sugar Profile of Coconut Sap

Among the various coconut derivative products, sap from the coconut flower is one of the most profitable for farmers. This sap is harvested from unopened coconut flowers or from the outer skin of the flowers and is then processed into a variety of versatile products. Coconut sap is recognized as a highly beneficial food product, as it can be consumed directly as a nutritious health drink and can also be processed into products such as syrup, honey, and coconut sugar. The diversity of products derived from coconut sap offers significant economic opportunities for farmers, as its market value is considerably higher compared to other coconut products (Sudha et al., 2019).

The sugar profile of the coconut sap sample was analyzed using High-Performance Liquid Chromatography (HPLC), a widely utilized analytical technique for precise quantification and identification of sugars. HPLC allows for the separation of sugar components based on their molecular interactions with the column material, providing detailed insights into the composition of a sample (Asghar et al., 2021). In this study, a HyperREZ column was employed with a specific elution protocol to detect various sugars, including sucrose, glucose, and fructose, among others. The analysis revealed the presence of both simple sugars and more complex carbohydrates, along with non-sugar components such as polyols, highlighting the comprehensive capability of HPLC in profiling the chemical composition of sap samples. The results of the HPLC analysis for the coconut sap sample are presented in **Table 1**, summarizing the concentrations and relative proportions of the identified compounds.

Table 1. HPLC Analysis

Component	Concentration (%)
Sucrose	3.152
Glucose	13.499
Fructose	1.430
Maltotriose	32.498
Maltose	37.911
Xylose	2.602
Mannose	1.423
Glycerol	2.509
Erythritol	0.921
Mannitol	1.517

Based on HPLC analysis, it is known that maltose (37.91%) and maltotriose (32.50%) are the main components in coconut sap, followed by glucose (13.50%) and sucrose (3.15%). Fructose was detected at a lower concentration (1.43%), along with other compounds such as xylose (2.60%), mannose (1.42%), and sugar alcohols like glycerol (2.51%), erythritol (0.92%), and mannitol (1.52%). These results differ from several previous studies that

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reported sucrose as the main sugar in coconut sap, with a concentration of about 6.91%, while glucose and fructose were approximately 2.53% and 3.48%, respectively (Asghar, Yusof, Mokhtar, Noriznan, et al., 2020). These differences may be caused by various factors, such as the coconut variety used, the environmental conditions where it grows, the method of sap collection, and the handling and storage of the sap before analysis (Wiboonsirikul et al., 2024).

Sucrose is known as the main component in sugar crystallization due to its ability to form stable and orderly crystals. However, in this sap sample, the sucrose concentration is relatively low (3.15%), while the levels of maltose and maltotriose are very dominant. The presence of maltose and maltotriose, which are highly soluble oligosaccharides, tends to inhibit perfect crystallization because they increase the viscosity of the solution and reduce the level of supersaturation required for sucrose crystal formation (Woodbury & Mauer, 2023). Additionally, glucose and fructose as reducing sugars can also interfere with the formation of the sucrose crystal lattice through a competitive precipitation mechanism, potentially resulting in sugar with irregular crystals, a softer texture, and a tendency to easily absorb moisture (Renzetti et al., 2025).

In general, producing stable crystalline coconut sugar is challenging due to the complicated sugar composition of coconut sap. Optimizing process variables such heating temperature, evaporation rate, and acidity level (pH) is also crucial to increase the sucrose crystallization rate and avoid crystallization problems brought on by the complex sugar content of coconut sap (Kencana et al., 2023). Accelerated creation of more homogeneous crystals can also be achieved by using auxiliary materials, such as pure sucrose seed crystals, in the correct ratios.

3.2 Sugar Production

The production of coconut sugar in this study employed a vacuum evaporation technique combined with the addition of winter melon fruit extract to enhance the quality and functional value of the product. The process began with the extraction of winter melon fruit, followed by concentrating the extract to 30°Brix (Subagyo & Achmad, 2010). The concentration process was carried out using vacuum evaporation to increase the concentration of bioactive compounds, ensuring a positive impact on the quality of the resulting sugar.

The pH of the coconut sap was measured before use in the sugar production process. The pH range of the coconut sap used was 5–6, consistent with previous studies that reported the normal pH of coconut sap to be approximately 5–5.8 (Adisetya et al., 2022). In addition to pH, the °Brix of the coconut sap was also measured, yielding a range of 13–15°Brix. The sugar production process began by heating 1 liter of coconut sap to a concentration of 60°Brix using a vacuum pressure of -900 mbar and a temperature of 80°C. This vacuum condition was designed to evaporate water while preserving the nutrients and active compounds in the sap (Asghar, Yusof, Mokhtar, Yaacob, et al., 2020).
Once the desired concentration was achieved, 10 ml of winter melon fruit extract was added to the coconut sap.

The mixture of coconut sap and winter melon fruit extract was continuously stirred using a magnetic stirrer at a speed of 250 rpm to ensure homogeneity. Evaporation was continued until the mixture reached a concentration of 74°Brix. At this stage, sugar seeds were added in varying weights according to the study design (0%, 5%, 7.5%, or 10%). The addition of sugar seeds accelerated the crystallization process, resulting in a more uniform and stable sugar structure (Upadhyaya et al., 2023).

The entire process of making coconut sugar takes quite a long time, around 10–12 hours, starting from the heating stage, evaporation, to crystal formation. This is due to the complex content of coconut sap as explained in the previous discussion. After the evaporation process is complete, the sugar is transferred to a clean container for the final drying stage. The drying process is carried out using a food dehydrator, which functions to ensure that the water content in the sugar is truly reduced to the maximum. This step is very important so that the produced sugar has good stability and a longer shelf life.

The winter melon fruit extract used in this process played a crucial role in increasing the bioactive compound content of the coconut sugar. In addition to enhancing the functional value (Saraiva et al., 2023). The final product, in the form of crystalline coconut sugar, serves as a healthier natural sweetener with a low glycaemic index and potential health benefits due to the active compounds derived from winter melon fruit. The well-controlled vacuum evaporation technique ensured high-quality sugar in terms of nutritional value, physical properties, and stability (Wei-xin et al., n.d.).

However, in this study, the analysis of the nutritional content in the final coconut sugar product has not been conducted. This is due to the limitations of laboratory resources and the primary focus of the research being directed towards the treatment's effect on physical characteristics (color and yield). Analysis of the nutritional content in the final product requires more complex methods, such as chromatography or spectroscopy tests, which necessitate special equipment and higher costs. Therefore, nutritional content analysis is recommended to be conducted at the advanced research stage, so that a more comprehensive understanding of the functional value of coconut sugar can be achieved. Further research is expected to identify the nutritional content present in the final product, as well as evaluate the potential health benefits of adding winter melon extract to the coconut sugar formulation.

3.3 The Effect of Adding Winter Melon Extract and Sugar Seeds on Product Color

Product color is a key indicator of visual quality, as it reflects the heating process, the level of caramelization, and crystallization during production. Coconut sugar is a processed product from coconut sap, known for its natural brown color and caramel-like taste. The brown color in coconut sugar is formed because of the caramelization process and the Maillard reaction that occur during heating, both in the syrup thickening stage and the crystallization process. However, the final color of coconut sugar can also be influenced by various other factors, such as the processing method, heating temperature, additives used, and the form of the final product, whether in crystal, block, or liquid form (Hebbar et al., 2022). In this study, an analysis was conducted to evaluate the effect of adding winter melon extract (Benincasa hispida) and sugar seeds on the color characteristics of the produced coconut sugar. Color evaluation was conducted using a colorimeter with the CIELAB model approach, where the L* value indicates the level of brightness or lightness, the a* value indicates the intensity of the red-green color, and the b* value indicates the intensity of the yellow-blue color (Harianingsih, 2018). The results of the colorimeter measurements can provide detailed and objective information regarding the visual changes in coconut sugar after additional treatment.

Table 2. Color Analysis

Variable			**L***	**a***	**b***
Coconut sap	**Extract**	**Sugar seed**			
1L	0 ml	0%	73,61	9,2	28,07
1L	10 ml	0%	62,06	9,78	22,73
1L	10 ml	5%	60,97	9,99	22,24
1L	10 ml	7,5%	60,44	9,41	22,51
1L	10 ml	10%	68,15	10,1	26,29

Table 2 shows the results of adding sugar seeds and winter melon extract. The addition of sugar seeds in varying amounts can influence the rate of crystallization, with a higher seed count tending to accelerate crystal formation and reduce heating time (Upadhyaya et al., 2023). The variation in sugar seed addition that combine with the addition of winter melon extract plays a crucial role in determining the color stability of the resulting sugar product. The variation in the addition of sugar seed to coconut sugar shows a quite clear effect on the resulting color parameters. Based on CIELAB data, it is known that the gradual addition of sugar seeds tends to increase the L*, a*, and b* values in coconut sugar products. This means that with the increasing addition of sugar seeds, the color of the sugar becomes brighter, and the intensity of the red (a*) and yellow (b*) colors also increases. This indicates that sugar seeds play a role in improving the visual appearance of coconut sugar, possibly through mechanisms that trigger more orderly crystallization and the formation of more uniform color. These results are supported by the research of Herlina et al. (2021), which states that the addition of sugar or similar components in food processing can help improve color stability by forming molecular bonds, thereby producing products with a more attractive and uniform appearance. Additionally, sugar seeds can function as crystal nuclei, helping to form more uniform sugar granules, thereby resulting in a more consistent color distribution in the product.

Higher sugar seed addition during the sugar production process significantly affects the final product's color. As the number of sugar seeds increases, the crystallization process occurs more quickly, thereby reducing the sap heating time (Rogers et al., 2021). Shorter heating times help minimize the occurrence of Maillard reactions and caramelization, two chemical processes responsible for the darkening of sugar color. The Maillard reaction occurs due to the interaction between reducing sugars and amino acids, forming brown-colored melanoidin pigments, while caramelization happens due to the breakdown of sugar at high temperatures under low moisture conditions (Karseno et al., 2018). By accelerating crystallization through the addition of sugar seeds, the intensity of both reactions is reduced, resulting in a brighter and more stable sugar product color compared to treatments without sugar seeds or with lower seed amounts. This aligns with research showing that controlling the heating time and temperature significantly affects the color quality of palm sugar, where excessive heating tends to result in an undesirable dark brown color for consumers (Buera et al., 2005).

Meanwhile, the addition of 10 ml of winter melon extract showed a different effect on the color characteristics of the coconut sugar product. The results of the colorimeter analysis showed a decrease in L* value from 73.61 to 62.06, indicating that the product became darker compared to the control without extract. Additionally, there was an increase in the a* value from 9.2 to 9.87, indicating an increase in the red hue of the product, while the b* value decreased from 28.07 to 22.73, showing a reduction in the intensity of the yellow color. This phenomenon aligns with previous research findings that state the addition of extracts or materials rich in bioactive compounds, such as flavonoids and polyphenols, can affect the stability and intensity of food product colors, particularly through the mechanism of antioxidant compounds interacting with color components (Purbowati et al., 2024). In other words, the more extract is added, the darker the product color tends to become, with a shift in hue towards red. These results indicate the potential of winter melon extract in influencing the visual characteristics of coconut sugar, while also opening opportunities for further research on the impact of bioactive compounds in modifying the color and quality of the final product.

3.4 The Effect of Adding Winter Melon Extract and Sugar Seeds on Product Yield

Yield refers to the ratio between the amount of output produced and the input used, reflecting the efficiency of the production process (Aulia R. Ramadhanti & Santosa, 2023). In research, efficiency is defined as the ability to generate maximum output using a given amount of input or to produce a specific amount of output with minimal input. Yield serves as an essential parameter to evaluate the effectiveness of production techniques and the potential for optimization in achieving higher productivity. This study aims to measure the yield of healthy sugar obtained from the

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evaporation of coconut sap combined with the addition of winter melon fruit extract and varying sugar seed weights as the independent variable. The yield calculations in this study were based on the volume of coconut sap used and the final weight of sugar produced (Natawijaya et al., 2018).

The process utilized 1 liter of coconut sap as the fixed raw material, with the addition of 10 ml of concentrated winter melon fruit extract to enhance the nutritional and functional properties of the sugar. The findings aim to determine the optimal conditions for achieving the highest production efficiency while maintaining the quality of the sugar produced. The research findings are presented in Table 3 and Figure 1

Table 3. Product Yield

Variable			Product Weight (gr)	Yield (%)
Coconut sap	**Extract**	**Sugar seed**		
1L	0 ml	0%	92,303	9,23
1L	10 ml	0%	93,145	9,31
1L	10 ml	5%	103,077	10,31
1L	10 ml	7,5%	103,347	10,33
1L	10 ml	10%	104,836	10,48

The addition of sugar seed (crystallization nuclei) in the sugar making process plays an important role in increasing the yield of the final coconut sugar product. Based on Table 3 without the addition of sugar seed, the product yield rises when sugar seed is added. It can be seen in Figure 1 that there is an increase of up to 1.72% on the graph along with the increasing addition of sugar seed given. The addition of 5%, 7.5%, and 10% sugar seed produces yields of 10.31%, 10.33%, and 10.48%, respectively. product yield only ranges between 9.21% and 0.23%. The The mechanism underlying this improvement involves the sugar seeds acting as nucleation points for crystallization, which accelerates the formation of sucrose crystals. This process not only prevents the hydrolysis of sucrose into glucose and fructose but also maximizes the volume of crystallized sugar, leading to a higher overall product weight. Furthermore, the controlled crystallization ensures that the sugar crystals are uniform in size and structure, enhancing the physical quality of the product (Natawijaya et al., 2018).

Beyond improving yield, the addition of sugar seeds also reduces the time required for the evaporation process. By initiating crystallization at an earlier stage, the process minimizes sucrose losses due to evaporation or thermal degradation. The presence of more crystallization nuclei ensures that sucrose in the sap efficiently precipitates into solid sugar, reducing waste and improving the conversion rate of raw material to final product (Verma et al., 2021). Moreover, the use of sugar seeds contributes to the aesthetic and functional properties of the sugar. Products with well-formed crystals tend to have better texture, appearance, and stability, making them more appealing to consumers.

The addition of winter melon extract also affects the product yield. With the addition of 10ml of extract, there was an increase of about 0.87%, from 9.23% to 9.31%. This indicates that the bioactive content in winter melon contributes to increasing the product yield due to the mixing of these compounds in coconut sugar.

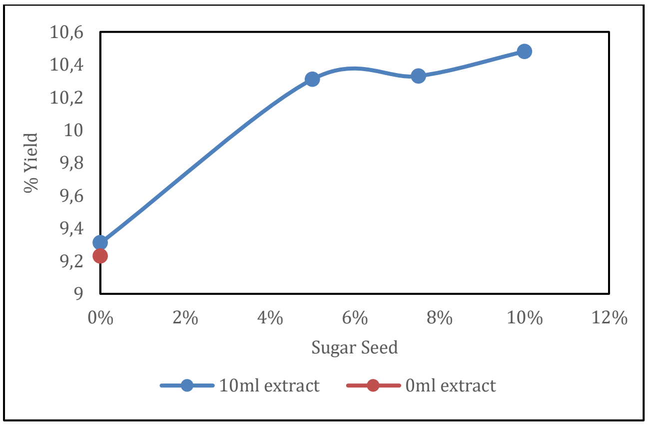

Figure 1. The Effect of Sugar Seeds Addition on Yield Product

The findings of this study underscore the significance of incorporating sugar seeds and winter melon extract into the coconut sap evaporation process to enhance production efficiency. The observed improvements in yield highlight the potential economic benefits for producers, particularly in reducing costs and maximizing resource utilization. For both small-scale and industrial-level production, the ability to generate higher yields with consistent quality provides a competitive advantage. Additionally, the integration of winter melon fruit extract further elevates the value of the final product by enriching it with bioactive compounds that offer potential health benefits. This study demonstrates the importance of process optimization in the production of functional food products, paving the way for more efficient and sustainable methods in the sugar industry (Jackson, 2005).

3.5 Evaluation of Sugar Quality through Water Activity Analysis

Water activity (aw) measures the amount of free water in a product that can support microbial activity. The aw value ranges from 0 (completely dry) to 1 (pure water), with lower values making it more difficult for bacteria, mold, and yeast to grow (Winona et al., 2024). Ideally, sugar products should have an aw below 0.65 to ensure product safety during long-term storage and minimize the risk of microbial contamination (Subbiah et al., 2020). In sugar-based products, the presence of free water can trigger undesirable reactions such as oxidation, fermentation, and microbial growth. While the total moisture content may vary, the key factor is the amount of water available in its free state.

Excessive free water increases the risk of microbial spoilage, ultimately reducing the product's shelf life (Ergun et al., 2010).

Table 4. Water Activity Analysis

Variable			Water Activity	Shelf-life Expactation
Coconut sap	Extract	Sugar seed		
1L	0 ml	0%	0,62	6-12 months
1L	10 ml	0%	0,61	6-12 months
1L	10 ml	5%	0,61	6-12 months
1L	10 ml	7,5%	0,61	6-12 months
1L	10 ml	10%	0,62	6-12 months

Table 4 presents the water activity (aw) analysis, showing consistent values between 0.61 and 0.62 across all treatments. Sugar produced without winter melon extract or sugar seed had an aw of 0.62, while adding 5% sugar seed slightly reduced it to 0.61. Similarly, treatments with 10 ml of winter melon extract and varying sugar seed concentrations (0%, 5%, 7.5%, and 10%) maintained aw within the same range. This stability suggests that formulation variations, including sugar seed and winter melon extract, do not significantly affect aw (Subbiah et al., 2020).

The stability of aw is linked to the interaction between water, sugar molecules, and other components. Winter melon extract binds water, preventing it from becoming free water, while sugar seed enhances crystallization, further reducing available moisture (Medeiros et al., 2019). This stability benefits shelf life by minimizing microbial contamination risks, making the sugar product safer and more durable for long-term storage (Vu et al., 2020). With a fairly stable aw value (0.61–0.62 for each variable), the product's shelf life is estimated to reach 6–12 months depending on storage conditions. This estimate refers to the general shelf life standards for food products with low aw values, where an aw value of 0.61–0.62 is considered sufficiently safe from the growth of microorganisms that can damage food quality and safety (Subbiah et al., 2020).

4. Conclusions

This research successfully developed a coconut sugar production process with the addition of winter melon extract using the vacuum evaporation method. In addition, sugar seed was also added in this process as a crystallization trigger. The research results show that the combination of adding winter melon extract and sugar seed can increase the product yield, with the highest yield reaching 10.48% in the treatment with the addition of 10 mL of extract and 10% sugar seed. In terms of color, the addition of winter melon extract tends to decrease the brightness level (L*) of the product, resulting in a darker color. However, the addition of sugar seeds helps increase the brightness of the product, with the highest brightness level also achieved in the combination of 10 mL of extract and 10% sugar seeds. These findings indicate the potential for developing coconut sugar with the addition of winter melon extract as a functional food product. Further research is recommended to focus on optimizing the production process, evaluating the nutritional content, and studying the product's storage stability to support these promising results.

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Statement
During the preparation of this work the authors used ChatGPT 4.0 and quilbot in order to improve English language and proofread the text. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement
Gabrilla Ulfa Megasari: Writing –review & editing, Writing – original draft, Visualization, Investigation, Formal analysis.
Siti Nurkhamidah: Validation, Resources, Conceptualization
Fahmi: Validation, Resources, Conceptualization

Declaration of competing interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability
The data that has been used is confidential.

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