DRF-490
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RESEARCH ARTICLE Asian Journal of Dairy and Food Research

Characteristics of Sugar Palm Sap Powder (*Arenga pinnata* Merr.) Produced using the Foam-mat Drying Method with Various Encapsulant Agents

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10.18805/ajdfr.DRF-490

ABSTRACT

Background: Sugar palm sap (*Arenga pinnata* Merr.) is a natural liquid from tapping sugar palm trees, rich in sugars and bioactive compounds such as antioxidants. inulin.

Methods: This study analyzes the characteristics of sugar palm sap powder produced using some encapsulant agents, including maltodextrin, dextrin, gum arabic and The analysis includes moisture content, yield, total phenolics, antioxidant activity and functional group identification using FTIR and crystallinity phase using XRD.

Result: The results show that gum arabic provides the highest total phenolic retention at 1.35 mg GAE/100 g and the highest antioxidant activity at 31.93%. Maltodextrin and dextrin offer the best physical stability. FTIR analysis revealed the presence of key functional groups such as O-H, C-H and C-O, while XRD confirmed that all samples are in an amorphous phase. Encapsulant affects the physical and bioactive properties of palm sap powder, with gum arabic excelling in bioactive compound retention. At the same time, maltodextrin and dextrin provide the best physical stability.

Key words: Antioxidant activity, Encapsulant agents, Sugar palm sap, Total phenolics content.

INTRODUCTION

The sugar palm (*Arenga pinnata* Merr.) is a versatile plant, with nearly all parts usable for various purposes. It is also widely consumed in Southeast Asia for its nutritional value and antioxidant content (Sartinah *et al.,* 2022). Its composition primarily consists of water and sugars such as glucose, fructose and sucrose, In addition, sugar palm sap contains protein, fat, minerals and ash content (Palachum *et al.,* 2023). The high sugar content, a favorable pH and the presence of microorganisms can cause sugar palm sap to ferment quickly, a white, foamy and sour product that requires immediate preservation. One effective method to extend its shelf life and simplify storage is processing it into an instant powder by encapsulation.

Instant beverages are powdered food products that dissolve quickly in water and are convenient to prepare. Foam-mat drying is a straightforward process for drying liquid or semi-solid products by mixing them with foaming agents and stabilizing agents to create a stable foam (Thuy *et al.,* 2024) and convert it into stable powders with enhanced shelf life and convenience (Prathengjit *et al.,* 2025). This method is particularly suitable for food products that are heat-sensitive, viscous, sticky, or have high sugar content. Therefore, encapsulating agents that also function as foam stabilizers are required in the foam-mat drying method. These agents aim to optimize the drying process, maintain product quality and prevent degradation during drying (Kumar *et al.,* 2023).

This study utilizes four different types of encapsulating agents: Maltodextrin (MD), dextrin (D), gum arabic (GA) and inulin (IN). These materials fall into the carbohydrate polymers category, commonly used as encapsulant agents in microencapsulation processes. Compared to proteins or lipids such as whey protein, soy protein, sodium caseinate and lecithin, carbohydrate polymers are more economical while still being effective as encapsulant agents. Their advantages lie in stabilizing pigments and bioactive compounds (Rezagholizade-shirvan *et al.,* 2024).

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How to cite this article: Anggraini, T., Azima, F., Anwar, A., Hervani, D., Suhendra, D., Wisnubroto, M.P., Noflindawati and Putra, A.R. (2025). Characteristics of Sugar Palm Sap Powder (*Arenga pinnata* Merr.) Produced using the Foam-mat Drying Method with Various Encapsulant Agents. Asian Journal of Dairy and Food Research. 1-7. doi: 10.18805/ajdfr.DRF-490.

Submitted: 23-12-2024 **Accepted:** 04-07-2025 **Online:** 18-07-2025

Maltodextrin and dextrin, derived from the partial hydrolysis of starch, have short glucose chains. Maltodextrin is a mixture of oligosaccharides with 3-20 glucose units, which can form a stable encapsulating matrix, dissolve easily in water and enhance product texture and stability. Dextrin has a more varied saccharide structure, allowing it to function as a thickening and stabilizing agent (Gawałek and Domian, 2020).

Gum arabic is a natural carbohydrate polymer derived from the sap of Acacia trees. Its benefits include excellent emulsifying properties and the ability to form a stable, protective layer around active compounds during drying (Kumar *et al.,* 2023). Inulin, a soluble dietary fiber, has the advantage of not being hydrolyzed in the upper digestive tract and fermented in the colon by gut microflora. This makes inulin a suitable encapsulating agent for products that do not raise the glycemic index, making it ideal for diabetes-friendly products (Ali, 2009). However, research has yet to specifically report the characteristics of palm sap powder dried using the foam-mat drying method with various encapsulating agents.

This study introduces the innovation of using multiple encapsulant materials (maltodextrin, dextrin, gum arabic and inulin) combined with the foam-mat drying method to produce sugar palm sap powder with optimized physicochemical and functional properties. The objective is to evaluate the physicochemical properties, antioxidant activity and bioactive compound retention and structural characteristics of the resulting powders.

MATERIALS AND METHODS

The experiment was conducted from October to December 2024 at the Laboratory of the Department of Food and Agricultural Technology andalas University and at the Central Laboratory, Andalas University.

Materials and tools

The primary plant material used in this study is sugar palm sap (*Arenga pinnata* Merr.) with the formulation including maltodextrin DE 18-20 (Alfa Food Chemical, Indonesia), dextrin (D) (Indoplant, Indonesia), gum arabic (GA) (Mitra Jaya Chemical, Indonesia), inulin (IN) (Yasma Natura, Indonesia) and Tween 80 as a foaming agent.

The chemicals used in this study are methanol, sodium carbonate (Na_2CO_3), Folin-Ciocalteu reagent (50%), distilled water, DPPH (2,2-Diphenyl-1-1-Picrylhydrazyl), KBr (potassium bromide) and gallic acid (GAE). Additionally, The instrumentation and tools used in this study include the hand-refractometer (Atago, Japan), UV-1800 Spectrophotometer (Shimadzu Co., Ltd., Kyoto, Japan), X-ray diffractometer (XRD) (Bruker, USA), Fourier transform infra red (FTIR) (Shimadzu Co., Ltd., Kyoto, Japan), hot plate, analytical balance, oven, desiccator and muffle furnace. Additionally, a mixer (Philips Mixer HR-1559, China), food dehydrator (Wirastar FDH-10, Indonesia) and herb grinder used for the production process.

Research procedure

Sample preparation

Sugar palm sap (*Arenga pinnata* Merr.) was obtained by tapping directly from the aren trees owned by local farmers in Nagari Koto Malintang, Agam Regency, Indonesia. The sap was tapped from the aren plants and immediately filtered before being placed into storage containers. It was stored in plastic bottles at a temperature of -22°C prior to use.

Formulation of aren palm sap powder

The formulation used in this study, including the materials and their quantities, is shown in Table 1.

The foam-mat drying process involved mixing sugar palm sap with encapsulant materials and a foaming agent (Table 1), then homogenized with a mixer for 18-20 minutes until a stable foam formed. The foam was spread on baking paper, dried in a food dehydrator at 70°C for 7-8 hours, ground into a fine powder, sieved through an 80-mesh sieve, packaged and stored in a desiccator for analysis.

Sugar palm sap powder analysis

Moisture, ash and yield content by gravimetry method and total soluble solids (Brix) by using a refractometer with a 0-93% Brix measurement range.

Total phenolic content (TPC) (Bala and Barmanray, 2019) with modifications

Aren palm sap powder was extracted by dissolving 1 g of sample in 10 mL of methanol, followed by ultrasonication for 25 minutes at 25°C. One mililiter of aren palm sap extract with methanol as solvent is added to 2 ml of distilled water, 1 ml of 50% Folin-Ciocalteu reagent and 1 ml of 5% Na_2CO_3 solution and then vortexed. The sample is stored in the dark for 1 hour at room temperature. Absorbance is then measured at a wavelength of 725 nm using a UV-Vis Spectrophotometer. TPC is determined using a standard calibration curve of gallic acid and expressed as a mg GAE/g sample.

Antioxidant activity (Badmus *et al.,* 2016) with modifications

1 mililiter of aren palm sap extract is added to 2 ml of 25 ìM DPPH solution, then vortexed. The sample is stored in the dark for 30 minutes at room temperature. Absorbance is measured at a wavelength of 517 nm using a UV-Vis Spectrophotometer. A blank is prepared using the same procedure, substituting the sample with methanol. The antioxidant activity is calculated using the following formula:

$$\%\ \text{Antioxidant activity} = \frac{\text{Abs blank - Abs sample}}{\text{Abs blank}} \times 100$$

Fourier transform infrared (FTIR) analysis (Safitri *et al.,* 2017)

15 milligrams of aren palm sap powder with different encapsulants were ground with 300 mg of dry KBr in a mortar until homogeneous. The mixture was pressed into a pellet under 10 tons of pressure and analyzed by FTIR over the 400-4500 cm^{-1} range, with results compared to literature data.

X-ray diffraction (XRD) analysis (Giannetti *et al.,* 2019)

The powder sample is prepared with a minimum volume of 2 mL and sieved through a 200 mesh sieve. The diffraction pattern of the sample is measured using an X-ray beam from a Cu anode tube and identified using EVA software.

Statistical analysis

The results of all experiments were expressed as mean ± SD of triplicate measurements.

RESULTS AND DISCUSSION

Analysis of palm sap powder

The results of the physical properties analysis of the instant aren palm sap powder beverage with different encapsulant material treatments are shown in Table 2,

The appearance of the palm sap powder product with different types of encapsulant can be seen in Fig 1.

% Yield

The yield analysis of sugar palm sap powder under different encapsulant treatments is shown in Table 2. Encapsulants with higher molecular weights, such as maltodextrin, dextrin, gum arabic and inulin, increase the glass transition temperature (Tg), reduce hygroscopicity and minimize stickiness (Fauziyah *et al.,* 2023). Low-molecular-weight sugars tend to be stickier and harder to dry without encapsulants (Linnenkugel *et al.,* 2021). This result is consistent with (Gawałek and Domian, 2020). Gum arabic, with high solubility (up to 50%) and low viscosity, forms foams with large surface areas, enhancing foam stability and final yield during drying (Kumar *et al.,* 2023). Inulin, a prebiotic fiber, also acts as an encapsulant; at 20% concentration, it achieved the highest yield (28%). High polymer concentrations reduce small molecule mobility, raise Tg and improve drying efficiency (Linnenkugel *et al.,* 2021).

Table 1: Formulation for producing of aren palm sap (*Arenga pinnata* Merr.) powder.

Ingridients	Encapsulant agent			
	MD (15%)	D (15%)	GA (10%)	IN (20%)
Aren palm sap (ml)	100	100	100	100
Maltodextrin (g)	15	-	-	-
Dextrin (g)	-	15	-	-
Gum arabic (g)	-	-	10	-
Inulin (g)	-	-	-	20
Tween 80 (ml)	2	2	2	2

Moisture content

The moisture content of instant palm sap powder with different encapsulants ranged from 4.09% to 7.78% (Table 2). Gum arabic produced powders with higher moisture content due to its strong hygroscopicity (Goula and Adamopoulos, 2008). Inulin, a polysaccharide with long chains and abundant hydroxyl groups, also exhibited high hygroscopicity (Wan *et al.,* 2020). In contrast, maltodextrin and dextrin, composed of shorter glucose chains with fewer hydroxyl groups, showed lower hygroscopicity and moisture content, resulting in more stable powders suitable for low-moisture applications.

Ash content

The ash content of sugar palm sap powder with different encapsulant treatments ranged from 0.66% to 2.32% (Table 2), reflecting the mineral content after drying. Inulin, a carbohydrate consisting of fructose chains, lacks mineral content. While natural sources of inulin, such as chicory root and Jerusalem artichoke, contain trace amounts of minerals, their contribution to ash content is negligible (Ahmed and Rashid, 2019).

Total soluble solids (°Brix)

Sugars like sucrose, fructose and glucose significantly contribute to TSS by binding free water, leading to higher

Table 2: Physical properties of sugar palm sap powder (*Arenga pinnata* Merr.).

Parameter	Encapsulant			
	MD (15%)	D (15%)	GA (10%)	IN (20%)
Yield (%)	23.59±1.00	24.63±0.35	20.33±1.93	28.03±1.90
Moisture (%)	5.06±0.48	4.09±0.51	7.78±0.17	7.63±0.58
Ash (%)	0.89±0.19	0.89±0.19	2.32±0.01	0.66±0.00
Total soluble solids (Brix)	8.2±0.53	8.7±0.64	9.3±0.58	8.4±1.2

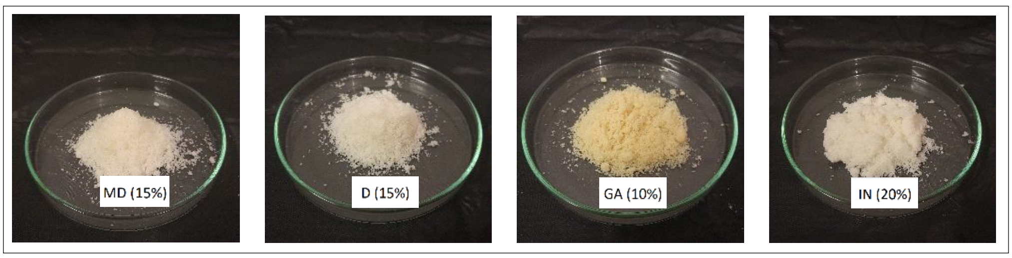

Fig 1: Appearance of sugar palm sap powder with different types of encapsulants.

TSS values in sugar-rich materials (Likumahua, 2022). *Arenga pinnata* sap had a TSS of 14.4°Brix (Table 2). Adetoro *et al.* (2020) observed a TSS decrease from 15.3°Brix to 10.4°Brix after powdering with encapsulants. Encapsulants such as maltodextrin, dextrin, gum arabic and inulin improve product stability by preserving structure. Their hydrophilic nature and abundant hydroxyl groups enable effective water binding (Siddiqui *et al.,* 2024).

Total phenolic content (TPC) and % antioxidant activity

The total phenolic content and percentage of antioxidant activity in powdered aren palm sap are presented in Fig 2 and 3.

The total phenolic content of sugar palm sap powder ranged from 0.84 to 1.35 mg GAE/100 g, depending on the encapsulant used: Gum Arabic (GA) 1.35 mg, Dextrin (D) 1.06 mg, Maltodextrin (MD) 0.84 mg and Inulin (IN) 0.86 mg. In comparison, (Badmus *et al.,* 2016) reported a higher phenolic retention (5.82 mg GAE/100g) in maltodextrin-encapsulated powder produced by spray drying. Antioxidant activity ranged from 25.10% to 31.94%, with GA (31.93%) showing the highest activity, followed by D (26.87%), IN (26.49%) and MD (25.10%). These values are comparable to those reported by (Badmus *et al.,* 2016), (26.81%-28.74%).

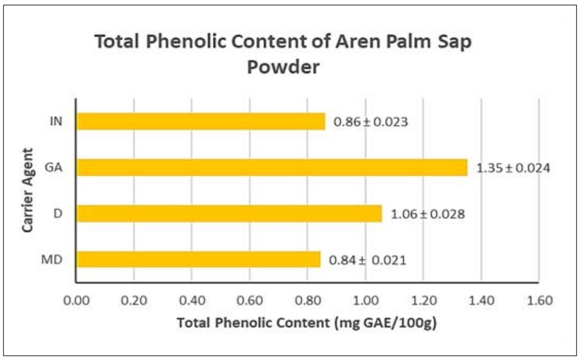

Fig 2: Total phenolic content of sugar palm sap powder.

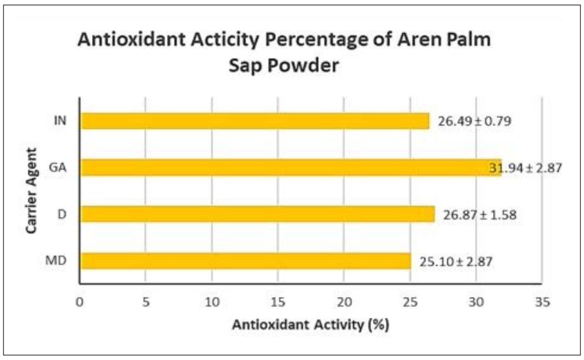

Fig 3: Antioxidant activity percentage of sugar palm sap powder.

This can be attributed to GA's superior emulsifying properties, which form a protective layer around the core material, preventing destructive changes during processing (Kania *et al.,* 2015). Hutasoit *et al.* (2023) compared the effectiveness of GA and MD in retaining phenolic content in powdered products. This result is consistent with (Iesa *et al.,* 2023), who reported that gum arabic enhances encapsulation by contributing to emulsifying and film-forming properties. Additionally, (Ayaz *et al.,* 2017) noted that gum arabic is a good source of phenolic compounds, providing strong antioxidant potential in food systems. The study revealed that MD lacks emulsifying properties, leading to less stable emulsions. The study also shows that D retains phenolic content better than MD. This aligns with findings by (Gawałek and Domian, 2020), highlighting tapioca dextrin's superior bioactive component retention compared to corn maltodextrin. Lower concentrations reduce excessive dilution, preserving more phenolic compounds in the final product (Iesa *et al.,* 2023).

Fourier transform infrared (FTIR) analysis

FTIR analysis was conducted to identify functional groups based on the influence of different types of encapsulant agents. Absorption peaks from FTIR spectra were compared across treatments using MD 15%, D 15%, GA 10% and IN 20%. The average FTIR spectra for each treatment are presented in Fig 4.

Table 3 presents the absorption peaks corresponding to functional groups in sugar palm sap powder with various encapsulant agents. Sugar palm sap predominantly contains sucrose, the primary sugar component (Victor and Orsat, 2018), with the chemical formula $C_{12}H_{22}O_{11}$ composed of C, O and H elements. Sucrose features several functional groups, including O-H, C-H sp^3 and C-O bonds (Kurniawan and Kustiningsih, 2019). FTIR spectra show prominent

Table 3: FTIR absorption peaks of aren palm sap (*Arenga pinnata* Merr.) powder.

Wave number of sugar palm sap powder treated with a coating agent (cm^{-1})				Wave number range (cm^{-1})	Functional group
MD (15%)	D (15%)	GA (10%)	IN (20%)		
3299.42	3276.6	3312.46	3281.78	3600-3200	O-H
2918.44	2918.07	2919.15	2919.39	3000-2800	C-H
-	-	1734.56	1734.64	1740-1700	C=O
1101.84	1103.87	1104.73	1104.74	1105	C-O
992.29	993.39	989.08	986.97	996	C=C
926.18	924.64	925.61	929.64	920	C-H
853.45	860.19	867.01	868.89	865	C-H

absorption in the ranges of 3600-3200 cm^{-1}, 3000-2800 cm^{-1} and 1105 cm^{-1}, confirming the presence of sucrose across all encapsulant agent treatments. The saccharide-specific absorption region (1100-850 cm^{-1}) further supports the presence of sucrose, as shown in Fig 4. These observations suggest that the sucrose component remains intact in the powdered sugar palm sap, regardless of the encapsulant agent used (Aziz *et al.,* 2022)

Additionally, Table 3 highlights absorption peaks in the 1740-1700 cm^{-1} range, indicating the presence of C=O bonds (carbonyl groups). FTIR spectra for GA and IN treatments specifically show absorption peaks at 1734.56 cm^{-1} and 1734.64 cm^{-1}, respectively, associated with carboxylic acids. Gum Arabic contains glucuronic acid groups, which are oxidation derivatives of glucose featuring terminal C=O bonds (Jumansyah *et al.,* 2017). The presence of these bonds explains the detection of carboxylic acid absorption at 1734.56 cm^{-1} for GA. Similarly, IN treatment shows absorption at 1734.64 cm^{-1}, also indicative of C=O bonds in the product. These findings align with previous research by (Andrianto *et al.,* 2022), which also identified similar C=O bond absorptions.

X-ray diffraction (XRD) analysis

X-ray diffraction (XRD) analysis was conducted to identify the crystalline phases present in sugar palm sap powder using different encapsulant agents. The crystalline phases were compared for each treatment: MD 15%, D 15%, GA 10% and IN 20%. The results are presented in Fig 5.

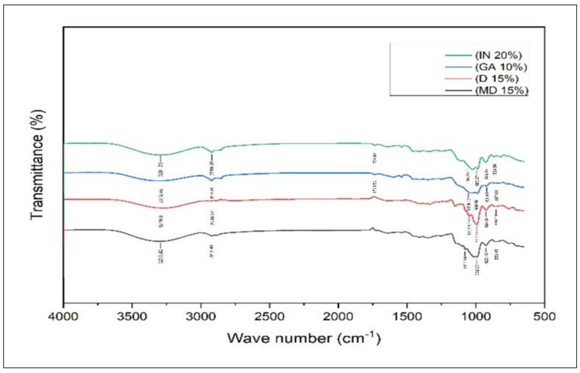

Fig 4: FTIR spectra of sugar palm sap powder based on encapsulant agent types.

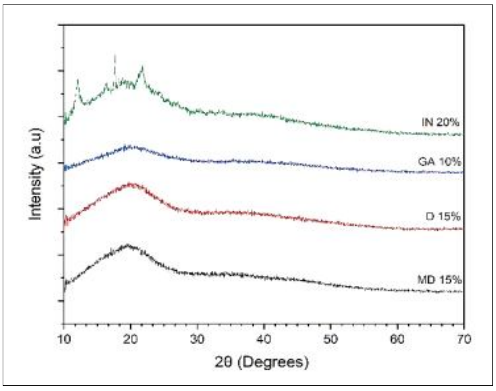

Fig 5: XRD analysis of aren palm sap powder with different encapsulant agents.

Fig 5 illustrates that the type of encapsulant agent did not significantly affect the crystalline phase of sugar palm sap powder. The diffraction patterns exhibit broad peaks with no sharp "peaks," indicating the amorphous phase of the powdered product. These results align with the findings on amorphous sucrose by (Nunes *et al.,* 2005), which demonstrated broad diffraction patterns in the range of 7-30^{o} 2θ, characteristic of materials lacking crystalline order. Powder in the amorphous phase dissolves in water more rapidly than its crystalline counterpart, making it particularly suitable for applications in the food industry, especially in instant beverage products (Siddiqui *et al.,* 2024). Additionally, amorphous powders have higher energy states, resulting in improved textural qualities, faster dissolution rates and enhanced solubility.

However, amorphous powders exhibit larger pore sizes compared to crystalline phases, leading to higher water absorption capacities (Nurhadi *et al.,* 2020). Encapsulant agents such as maltodextrin, dextrin, gum arabic and inulin are amorphous in structure and interact effectively with sucrose molecules during drying. These interactions stabilize sucrose structures by inhibiting crystallization, as noted in studies by (Pereira *et al.,* 2024; Pilicheva *et al.,* 2021).

Analysis of inulin revealed slight crystallization in the 2θ range around 12^{o} and 20^{o}. It is hypothesized is that the increase in water content in the product may influence the crystal formation. This is consistent with the findings of (Saavedra-Leos *et al.,* 2014), which suggest that increased water activity enhances the mobility of molecules within the system, thereby facilitating the transition from an amorphous to a crystalline state.

CONCLUSION

The results indicated that inulin achieved the highest yield, while maltodextrin and dextrin offered the best moisture content and physical stability. Gum arabic retained the highest total phenolic content and antioxidant activity, though its high moisture content affected its physical properties. Structural analyses revealed an amorphous state in all samples, with inulin showing crystalline peaks due to higher moisture. Gum arabic excels in bioactive retention, while maltodextrin and dextrin provide better physical properties. Future studies should explore combining gum arabic with maltodextrin or dextrin to optimize both bioactive retention and stability in sugar palm sap powder.

ACKNOWLEDGEMENT

This research was funded by the DRTPM Ministry of Education, Culture, Research and Technology, Indonesia. Master contract number 041/E5/PG.02.00.pl/2024. Date of Master contract 11 June 2024. Derivative contract number

142/UN16.19/PT.01.03/PL/2024 and the date 13 June 2024.

Disclaimers

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Informed consent

No animal testing in this research.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish or preparation of the manuscript.

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