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Evaluation of the Physicochemical Properties of Spray-Dried Coconut Flower Nectar Powder

H.N.Q. Anh, L.P.T. Quoc

Institute of Biotechnology and Food Technology, Industrial University of Ho Chi Minh City, Ho Chi Minh City, 700000 Vietnam

Abstract

This study aimed to determine the physicochemical properties of coconut flower nectar (CFN) powder produced by spray drying. The powder product of the best sample (with maltodextrin–CFN ratio of 26%, w/v) appeared as white, spherical, or oval particles. Its physicochemical properties were as follows: recovery yield (42 ± 2 %), moisture content (3.1 ± 0.6 %), particle size (3–12 μm), bulk density (0.380 ± 0.006 g mL^{-1}), hygroscopicity (22 ± 2 %), water solubility index (97 ± 1 %), angle of repose (42.2 ± 0.7°), and wettability (366 ± 11 s). The obtained results offer valuable insights for future research on spray drying of food products and pave the way for potential large-scale use of spray-dried CFN in a great variety of products due to easier preservation and longer shelf life.

Keywords: coconut flower nectar, spray drying, physicochemical properties, powder, sugar

Introduction

The coconut tree, *Cocos nucifera* L. (Arecaceae), is the most common plant in tropical regions. Some major coconut-producing countries are Indonesia, the Philippines, India, and Vietnam. The coconut industry is playing a very important role in the socio-economic development of Vietnam and should be considered an indispensable part of the country's development strategies. Vietnam has more than 132 000 ha of coconut trees, with a potential coconut growing area of about 220 000–250 000 ha [1].

Among many coconut products, coconut flower sap, also known as coconut flower nectar (CFN), stands out as the most remunerative one for farmers. It can be used as a nutrient-rich health drink or processed into syrup, honey, coconut sugar, and vinegar [2, 3]. This material offers numerous health benefits. It aids in digestion and fights diabetes, cancer, electrolyte deficiency, and even hair loss [4]. CFN has good antioxidant properties and is rich in vitamin C (116.19 μg mL^{-1}), ash (0.27%), as well as potassium (960.87 mg L^{-1}), sodium (183.21 mg L^{-1}), magnesium (22.91 mg L^{-1}), etc., thus suggesting a high content of minerals [5]. In addition, it has a low sugar content (15%) and a low glycemic index (GI 35), making it beneficial for people with diabetes [3].

Spray drying, a mechanical microencapsulation technique developed in the 1930s, has become a popular method to maintain the nutritional quality and extend the shelf life of food products. It is also especially effective for converting a liquid into a powder. The process involves using spray drying equipment to dry solutions and suspensions in a dispersed state and to remove moisture from the material, which helps increase durability and preservation. The carrier acts as a protective barrier for the raw material, limiting the influence of the external environment, preventing the loss of volatile substances, and maintaining the desired product conditions [6]. Microencapsulated materials are colloids such as gum arabic, starch derivatives, sugars (lactose, sucrose, maltose), maltodextrin, etc. [7]. Among them, maltodextrin (MD), which is a carbohydrate derivative, has been the most widely used carrier agent in spray drying. The quality of the spray-dried product depends on the dextrose equivalent (DE). MD is often used alone or in combination with other carriers (gum arabic) to improve the desired product properties [8]. Furthermore, MD is both very cheap and easy to buy, so it is extensively applied in the food industry, particularly in spray drying technology.

CFN is readily available in rural areas and undergoes natural fermentation easily due to the high sugar content in the initial raw material. To diversify products and increase the preservation time of CFN, spray drying is necessary: it decreases the water activity in the nectar and transforms it into a powder. In this study, spray drying is explored as an option to create an unfermented CFN product, which can be stored for a long time. The physicochemical indexes of this CFN product are analyzed for potential large-scale application in the future.

1. Material and Methods

1.1. Material. CFN was collected from 3 to 10-year-old coconut plants in Ben Tre province (Vietnam) in January 2023 (16°Brix) and frozen until use. MD (DE 12) was purchased from Roquette Frères (France).

1.2. Sample preparation. CFN was defrozen and mixed with MD at different concentrations (18, 22, 26, and 30%, w/v). The samples were coded M_{18}, M_{22}, M_{26}, and M_{30}, respectively. The sample with the initial MD concentration was coded M_0. The samples $M_{18\text{-}30}$ were adjusted with distilled water to obtain total soluble solids (TSS) of approximately 22°Brix. The mixture was spray-dried using a SD-Basic spray dryer (LabPlant, UK) with inlet/outlet air temperatures 180 °C/70 °C, pressure 4 bar, air flow rate 70 $m^3\ h^{-1}$, and feed flow rate 750 mL h^{-1}. The resulting powder product was vacuum-packed and stored at 25 °C.

1.3. Encapsulation yield (EY). EY was measured as the ratio of the dried mass of the obtained powder to the dried mass of the initial substances [9].

1.4. Bulk density (BD). The powder (2 g) was added into an empty graduated cylinder (10 mL) and shaken by hand for 1 min. The BD value was determined by the ratio of the mass of the powder to the volume occupied in the cylinder [10].

1.5. Water solubility index (WSI). According to the procedure described by Quoc with minor modifications [8], the CFN powder (2 g) and deionized water (25 mL) were vigorously mixed and incubated in a water bath for 30 min at 37 °C. Then, the mixture was centrifuged for 30 min at 6000 rpm. The supernatant was separated and dried in an oven at 103±2 °C. The WSI value (%) was expressed as the percentage of dried supernatant to the amount of the original powder.

1.6. Flowability. According to Geldart et al. with slight modifications, flowability was determined by measuring the angle of repose (AOR) [11]. A funnel was held at a fixed height on a flat base (5 cm), and the powder (15 g) was slowly poured through the funnel to form a cone. Then, the AOR was calculated as the inverse tangent of the ratio of the height and half of the width (radius) of the base of the cone.

1.7. Wettability. The powders were poured into a funnel positioned at a fixed height and dropped into 100 mL of water in a beaker (250 mL) at room temperature. After that, the time for the whole amount of the powder to visibly sink beneath the water surface was recorded as an indicator of wettability [12].

1.8. Hygroscopicity. About 1.5 g samples were placed in an airtight plastic container with a saturated solution of sodium carbonate and stored at 25 °C. After 7 days, these samples were weighed. Their hygroscopicity was determined as the amount (g) of adsorbed moisture per 100 g solids (g 100 g^{-1}) [13].

1.9. Scanning electron microscopy (SEM). The morphology of the spray-dried powder was examined under a Jeol JSM-IT200 scanning electron microscope (JEOL Ltd., Japan) at 1000× magnification.

1.10. Statistical analysis. The experimental data were processed using the one-way analysis of variance (ANOVA) method, and significant differences among the means from triplicate analysis at $p < 0.05$ were determined by Fisher's least significant difference (LSD) test using Statgraphics Centurion XV software (StatPoint Technologies, USA). The values obtained were expressed as the mean ± standard deviation (SD).

2. Results and Discussion

2.1. Moisture and EY of the CFN powder. Table 1 shows that the moisture content of all powder products (M_{0-30}) varied from 1.0 ± 0.3 % to 4.7 ± 0.2 %. These findings are consistent with previous studies. For instance, the moisture contents of the spray-dried pineapple and saffron petal powder range from 1.66 to 3.85% [12, 14]. With the addition of MD, the TSS content of the initial solution increases, leading to a decrease in the moisture content of the product [15]. The low moisture content indicates that the material has been effectively spray-dried and can be preserved for a long time. The EY values of the spray-dried samples from this study were relatively low, ranging from 12.4 ± 0.6 to 42 ± 2 %. Among them, the M_{26} sample possessed the greatest EY of 42 ± 2 %, which is still lower than in the *Polygonum multiflorum* Thunb. extract powder (60.4–65.17 %) [16], but significantly higher than in the *Morinda citrifolia* L. and *Beta vulgaris* L. fruit extract powder (5.67–8.02 %) [17].

Table 1.

Encapsulation yield (EY) and moisture content of the CFN powder

Sample	Moisture (%)	EY (%)
M_0	4.7 ± 0.2^c	–
M_{18}	1.0 ± 0.3^a	12.4 ± 0.6^a
M_{22}	4.5 ± 0.4^c	16 ± 2^a
M_{26}	3.1 ± 0.6^b	42 ± 2^c
M_{30}	3.2 ± 0.6^b	32 ± 6^b

Within the columns, the letters $^{a–c}$ indicate significant differences ($p < 0.05$).

Normally, the recovery efficiency of most spray-dried products does not exceed 90% due to the product residue that remains on the chamber wall after drying, thereby leading to a decrease in the recovery efficiency. The TSS concentration in the initial material and the carrier properties also significantly affect the recovery efficiency of the product. In addition, according to Phisut, EY depends on many factors, such as drying temperature, pump flow rates, raw material source, etc. [15].

2.2. Bulk density (BD), hygroscopicity, and water solubility index (WSI) of the CFN powder. Based on the results of Table 2, the BD value of the M_0 powder (0.52 ± 0.01 g mL^{-1}) was lower than that reported by Quoc (0.67 g mL^{-1}) for the spray-dried pineapple juice powder with MD as a carrier agent [8]. However, the BDs of the CFN powder ($M_{18\text{-}30}$) decreased more rapidly compared to that of M_0 and fluctuated from 0.30 ± 0.02 to 0.39 ± 0.02 g mL^{-1}. When compared to other carrier agents, such as gum arabic, the BDs of both the initial material and the powder product were significantly lower than those in the study by Quoc and Muoi [16]. The obtained results prove that the BD of a powder product strongly depends on the carrier nature. A low BD means that the powder product requires a larger packaging volume, which is also a weak point.

Table 2.

Bulk density (BD), hygroscopicity, and water solubility index (WSI) of the CFN powder

Sample	BD (g mL^{-1})	Hygroscopicity (%)	WSI (%)
M_0	0.52 ± 0.01^d	10 ± 2^a	94 ± 2
M_{18}	0.30 ± 0.02^a	17 ± 2^b	98 ± 1
M_{22}	0.330 ± 0.006^b	20 ± 1^{bc}	94 ± 2
M_{26}	0.380 ± 0.006^c	22 ± 2^c	97 ± 1
M_{30}	0.39 ± 0.02^c	21 ± 3^c	97 ± 2

Within the columns, the letters $^{a–d}$ indicate significant differences ($p < 0.05$).

The hygroscopicity of the initial material (MD) only reached 10 ± 2 %. However, after the spray drying process, the hygroscopicity of the $M_{18\text{-}30}$ products dramatically increased from 17 ± 2 to 22 ± 1 % ($p < 0.05$), especially for the samples with a higher amount of MD. These findings contradict the results of Mishra et al. [18]. MD can also be considered a long-chain sugar with hygroscopic properties. A higher amount of MD may lead to an increase in hygroscopicity and make preservation difficult. In fact, many factors directly affect hygroscopicity, including inlet temperature, air flow rate, feed flow rate, particle size, atomizer speed, as well as carrier agent type and concentration [15]. Therefore, adjusting hygroscopicity as desired is not easy for a spray drying process.

The water solubility index (WSI) of the CFN powder was high, ranging from 94 ± 2 % to 98 ± 1 %. It remained almost unchanged when MD was added to the initial material. There was a direct relationship between WSI and the powder product quality—the higher the WSI, the better the quality. These results were very similar to those in the study by Mishra et al. (93.28–94.11 %) [18], but higher when compared to gac powder (37.13–37.62 %) [19]. The good WSI of the CFN powder could be due to the significant level of carbohydrates (MD and sugar) in the materials.

2.3. Wettability and flowability of the CFN powder. The flowability before and after spray drying was evaluated through the angle of repose (AOR) tests (Table 3). The AOR of the powder products ($M_{18\text{-}30}$) ranged from $41.0 \pm 0.8°$ to $42.2 \pm 0.7°$, while that of the MD (M_0) was $59 \pm 3°$. This means that the flowability of the samples decreased significantly after the spray drying process, resulting in reduced adhesion. The flowability of the CFN powder was quite similar to that of the pineapple juice powder with MD used as a carrier agent (40.54°) [8], and the powder product showed cohesiveness properties (30° < AOR < 45°) [20, 21]. Generally, differences in flowability values of materials can be attributed to storage temperatures, moisture content of particles, relative humidity, particle shape, and particle size.

Table 3.

Wettability and flowability of the CFN powder

Sample	Flowability (AOR, °)	Wettability (s)
M_0	59 ± 3^b	497 ± 23^c
M_{18}	41 ± 1^a	224 ± 37^a
M_{22}	41.0 ± 0.8^a	206 ± 33^a
M_{26}	42.2 ± 0.7^a	366 ± 11^b
M_{30}	42 ± 3^a	409 ± 28^b

Within the columns, the letters $^{a–c}$ indicate significant differences ($p < 0.05$).

Table 3 shows that the wettability of the CFN powder sharply decreased from 497 ± 23 to 206 ± 33 s after the spray drying process. These results were also higher than those for the pineapple juice (179 s) and *P. multiflorum* extract powder (155 s) [8, 16]. Wettability is influenced by many factors, with the shape, particle size, moisture content, and particle cohesiveness being particularly important.

2.4. Microstructure and particle size of the CFN powder. The M_{26} sample had the highest EY, and its other properties were similar to those of other powder products. The MD (M_0) and M_{26} microstructures were observed, and the particle sizes were estimated. As shown in Fig. 1, *a*, the size of the M_0 particles varied greatly, from 20 to 44 μm in length and from 11 to 21 μm in width. The M_0 particles had amorphous shapes. Compared with previous studies, their shapes were similar to the SEM results obtained by Khazaei et al. [14] and Quoc [12] who used MD (DE 16-20) and gum arabic as a carrier agent. However, the CFN powder products were spherical in shape, with mutual adhesion between the particles, and the sizes of the particles were quite diverse, ranging from 3 to 12 μm (Fig. 1, *b*).

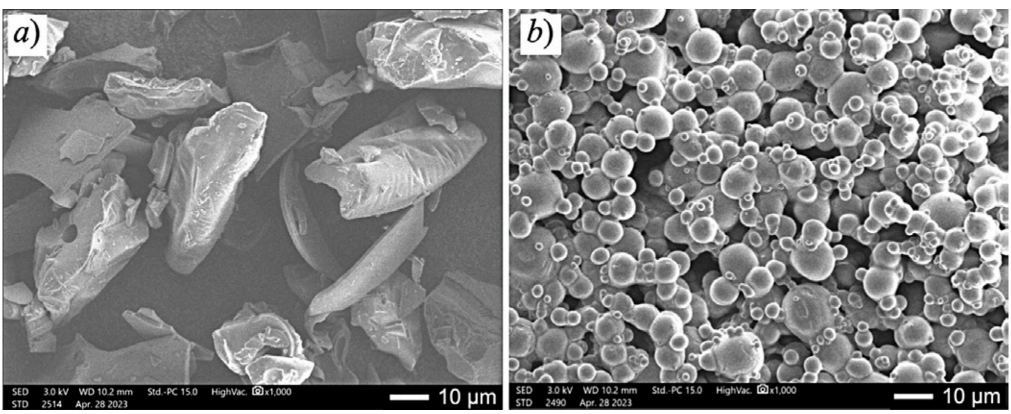

Fig. 1. SEM microphotographs of MD (*a*) and M_{26} sample (*b*) at 1000× magnification.

The particle sizes of the CFN powder were also in agreement with those of the *Orthosiphon stamineus* extracts powder in the studies by Pang et al. [22] with the particle sizes ranging from 4.87 to 6.93 μm when using MD and from 4.09 to 9.3 μm using whey protein isolate as the carrier agent.

There were no wrinkles or indentations on the particle surface. They were rounded and smooth, which is different from what was found by Quoc and Muoi [16] and Pang et al. [22]. The spray-dried products from these studies often had dents and wrinkles due to grain shrinkage as a result of moisture loss during the spray drying and cooling in the drying chamber. However, this phenomenon was not observed in our study. According to Loksuwan [23], the smooth surface of the product particles could be attributed to the high sugar content. Sugars may act as a plasticizer preventing shrinkage of the surface during drying.

Conclusions

CFN microencapsulation with the use of MD as an encapsulating agent proved to be effective during spray drying. It was found that CFN has great potential for commercial production of coconut sugar. The physicochemical properties of the spray-dried CFN are comparable to some other spray-dried plant materials. Depending on the MD concentration, the resulting powder products differ in their physicochemical properties and can be either spherical or oval-shaped. The M_{26} sample turned out to be the best encapsulating material for spray drying of CFN, with an EY of 42%. Overall, the results contribute to a better understanding of the CFN powder characteristics and the production of spray-dried powders with desired properties.

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Conflicts of Interest. The authors declare no conflicts of interest.

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Huynh Nguyen Que Anh, MSc in Food and Beverage Technology, Lecturer

Institute of Biotechnology and Food Technology, Industrial University of Ho Chi Minh City
Ward 4, Go Vap District, Ho Chi Minh City, 700000 Vietnam
E-mail: *huynhnguyenqueanh@iuh.edu.vn*

Le Pham Tan Quoc, PhD in Food Science and Technology, Lecturer

Institute of Biotechnology and Food Technology, Industrial University of Ho Chi Minh City
Ward 4, Go Vap District, Ho Chi Minh City, 700000 Vietnam
E-mail: *lephamtanquoc@iuh.edu.vn*

ОРИГИНАЛЬНАЯ СТАТЬЯ

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Оценка физико-химических свойств порошков из нектара цветков кокосовой пальмы, полученных методом распылительной сушки

Х.Н.К. Ань, Л.Ф.Т. Куок

Институт биотехнологий и пищевых технологий, Промышленный университет Хошимина, г. Хошимин, 700000, Вьетнам

Аннотация

В статье проанализированы физико-химические свойства порошков, изготовленных из нектара цветков кокосовой пальмы путем распылительной сушки. Наилучшие показатели получены для образца с концентрацией мальтодекстрина 26% (масс.), порошок которого имел вид белых, сферических или овальных гранул, а также обладал следующими характеристиками: выход продукта (42 ± 2 %), влажность (3.1 ± 0.6 %), размер частиц (3–12 мкм), насыпная плотность (0.380 ± 0.006 г/мл), гигроскопичность (22 ± 2 %), индекс растворимости в воде (97 ± 1 %), угол естественного откоса (42.2 ± 0.7°) и смачиваемость (366 ± 10 с). Полученные результаты имеют значение для дальнейших исследований в области применения распылительной сушки в пищевой промышленности и открывают новые перспективы для широкого использования порошков кокосового нектара за счет упрощения процесса его переработки и улучшения сохранности.

Ключевые слова: нектар цветков кокосовой пальмы, распылительная сушка, физико-химические свойства, порошок, сахар

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Хюон Нгуен Ку Ань, магистр наук в области технологии продуктов питания и напитков, преподаватель

Институт биотехнологий и пищевых технологий, Промышленный университет Хошимина
р-н. 4, г.о. Го Вап, г. Хошимин, 700000, Вьетнам
E-mail: *huynhnguyenqueanh@iuh.edu.vn*

Ле Фам Тан Куок, доктор философии в области наук о продуктах питания и их производстве, преподаватель

Институт биотехнологий и пищевых технологий, Промышленный университет Хошимина
р-н. 4, г.о. Го Вап, г. Хошимин, 700000, Вьетнам
E-mail: *lephamtanquoc@iuh.edu.vn*

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