TECHNICAL PROPERTIES AND PRESERVATION ABILITY OF SPRAY-DRIED RED-FLESH DRAGON FRUIT (*HYLOCEREUS COSTARICENSIS*) POWDER

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DOIs: https://www.doi.org/10.46242/jstiuh.v75i3.5264

Abstract: Red-fleshed dragon fruit (*Hylocereus costaricensis*) is a tropical fruit rich in antioxidants and bioactive compounds but highly perishable. This study investigated the effect of maltodextrin (DE 11.9) at Brix 15 and Brix 20 on the recovery efficiency, physical properties, bioactive compound content, and storage stability of spray-dried dragon fruit powder. The results demonstrated that increasing maltodextrin concentration from Brix 15 to Brix 20 significantly improved product yield (from 57.01% to 65.21%) while reducing the drying rate and spray drying capacity. Physical characteristics were also influenced, with higher maltodextrin levels leading to increased water absorption index (from 11.01% to 34.15%), reduced water solubility index (from 93.09% to 90.24%), larger particle size, and lighter color. However, the retention of total polyphenols (TPC), total flavonoids (TFC), and betacyanin was higher in Brix 15 powder. Stability tests at 50°C showed that both formulations exhibited good retention of bioactive compounds over six weeks, but Brix 15 powder maintained better stability, particularly in terms of TPC and TFC content. These findings highlight the potential application of spray-dried dragon fruit powder as a functional food ingredient, with Brix 15 providing better bioactive retention while Brix 20 enhances process efficiency.

Keyword: betacyanin, physical properties, polyphenols, red-fleshed dragon fruit, spray drying, stability.

1. INTRODUCTION

Consumers are increasingly worried about their health and looking for natural products, making the research and application of natural colorants more important. Natural colorants not only add natural and appealing color to products, but they also have numerous valuable biological activities and the potential for widespread use in a variety of industries, including food, pharmaceutical, and cosmetics. Studies on the utilization of betalains as natural color supplies in food system models are sparse, and more research is needed to demonstrate their potential [1]. Cactus fruit contains a high concentration of betalains, unlike red beets, which can be utilized in recipes without affecting flavor. The Cactaceae family includes the red dragon fruit (*Hylocereus polyrhizus*), which is native to Mexico, Central America, and South America [2]. Betacyanin is responsible for its rich purple color since it is the commonly studied betacyanin and has been proven to have a variety of health benefits [3]. However, the stability of natural colors should be considered in comparison to manufactured pigments [4,5]. As a result, research in this area is essential and of significant interest to the food sector. Many factors affect betalain stability, including temperature, oxygen, pH, water activity, and the presence of light [6–9]. Microencapsulation and other technologies can help to reduce the influence of degradation parameters. Spray drying is the most often used method for microencapsulating foods. However, the type of encapsulating agent and the food matrix might have an impact on the quality and effectiveness of the final product, as the encapsulating agent is particularly crucial in the microencapsulation process [10,11].

The spray drying technique has provided a promising new avenue for processing and preserving dragon fruit hues, particularly the nutritious, red-fleshed fruit. This approach not only helps preserve natural colors, distinctive flavors, and unique biological ingredients like betacyanin, but it also produces a wide range of products to fulfill the market's growing demands. Dragon fruit powder that has been spray-dried has a wide range of applications, including functional foods, drinks, natural food colors, and cosmetics. However, the application of this technology confronts some problems. Stickiness and flow rate issues are important challenges in the spray drying process for sugar-rich fruit juices [12,13]. These issues stem from the high concentrations of sugars with low molecular weights (MW) and organic acids in natural fruit juices with low glass transition temperatures (Tg). Fruit juices are frequently treated with high MW additions such as maltodextrin, starch, gelatine, and gum arabic before spray drying [14]. Maltodextrin is the most widely used food ingredient because of its high solubility in water, low viscosity, light taste, and colorless solution [14,15]. They have also been shown to preserve delicate food elements like flavor, color, and bioactive substances from adverse environmental conditions [16]. The issue of maintaining product quality after drying is also a big challenge, as temperature, humidity, and storage duration all have an impact.

The study aimed to identify and compare the important technical aspects of spray-dried dragon fruit powder generated with varying additive quantities, such as solubility, water absorption, moisture content, color features, and particle size. Furthermore, the study focused on analyzing the durability of highly active bioactive chemicals such as TFC, TPC, and betacyanin during storage to increase the effect of additive concentration on final product quality.

2. STUDY OBJECTS AND METHODS

2.1 Material

Red-fleshed dragon fruit (Hylocereus polyrhizus) was purchased in Go Vap area, Ho Chi Minh City. Raw materials are selected and purchased according to the following criteria: evenly ripe fruit, no damage, no pests, no bruising.

Maltodextrin DE 11.9, moisture 4.03%, pH= 5.3 is provided from MC Andrew And Partners Company Limited. NaOH, Na2CO3, NaNO2, AlCl3, gallic acid, Quercetin acid, Folin – Ciocalteu (Merck), Mcllvaine (pH = 6.5) were provided by Hoa Nam chemical company. Address No. 239/4 Ly Thuong Kiet, Ward 15, District 11, Ho Chi Minh City.

2.2 Preparation of material extract

Dragon fruit ingredients are pre-processed by removing the thorns, washing them, and then cutting the flesh and peel into little pieces. The pre-processed ingredients are mixed with water at a 1:5 (w/w) ratio, then ground and extracted at 60˚C for 5 minutes. The resultant extract was kept at 4°C for further analysis.

2.3 Spray drying process

The filtered extract was added with maltodextrin until it reached 15° and 20° Brix concentrations, after which the sample was homogenized at 5000 rpm for 5 minutes. After mixing, the mixture is delivered to spray drying (using a laboratory-scale spray dryer Model SD - Basic, LabPlant - England, capacity 1 liter/hour) at an input temperature of 160˚C, with an initial temperature output of 90˚C and an input flow rate of 350 mL/h. Following the spray drying process, the powder is collected in a clean container and stored in a desiccator until it cools. The powder was weighed, sealed, and stored at 4℃ in the dark for future examination.

2.4. Analytical method

Product yeild (PY) in spray drying: PY is the percentage between the amount of dry matter in the product obtained after drying and the amount of dry matter in the fruit juice before spray drying [17].

$$PY\ (\%) = \frac{Mass\ of\ product\ obtained}{Mass\ of\ initial\ solid} \times 100 \quad (1)$$

Drying ratio (DR) in spray drying: DR represents the amount of water removed from the input material compared to the total amount of material entering the drying chamber.

$$DR\ (\%) = \frac{(Mass\ of\ intial\ solution - Mass\ of\ product\ obtained)}{Mass\ of\ intial\ solution} \times 100 \quad (2)$$

Spray drying productivity (SP): is a measure of the effectiveness of the spray drying process. It reflects the ability to convert an input solution into a dry product within a certain period. Higher yields indicate more efficient spray drying.

$$SP\ (kg/h) = \frac{Mass\ of\ dry\ matter\ obtained\ (kg)}{Drying\ time\ (h)} \quad (3)$$

2.5 Physical properties

Water Absorption Index (WAI): is a measurement that evaluates the ability of spray-dried powder to absorb and retain water. WAI is calculated based on the weight of sediment and the weight of dry solids in the original sample [18]. Accurately weigh the powder sample into a pre-weighed dry centrifuge tube, add 10mL of distilled water, gently stir the mixture to completely contact the powder. Cover and let the mixture stand for 30 minutes, then centrifuge at 3000 rpm for 15 minutes. The upper liquid is carefully poured away, weighing the amount of gel remaining in the centrifuge tube [19]. Then, WAI is calculated according to the formula:

$$WAI\ (\%) = \frac{Mass\ of\ contrifuge\ tube\ with\ gel - Mass\ of\ contrifuge\ tube}{Mass\ of\ sample} \times 100 \quad (4)$$

Water solubility index (WSI): is an important measurement to evaluate the solubility of spray-dried powder in water. WSI is expressed as a percentage of the mass of the soluble fraction over the mass of the initial dry matter [20]. Accurately weigh the powder sample into a beaker, add 30 mL of water, stir the mixture for 10 minutes. Then filter the mixture through a pre-weighed dry filter paper, rinse the beaker and stirring rod through the filter paper to remove all insoluble powder. Dry the filter paper in a drying oven at 100°C until the weight is constant, reweigh the filter paper containing the insoluble part after drying. Then, WSI is calculated according to the formula:

$$WSI\ (\%) = \frac{m - (m_2 - m_1)}{m} \times 100 \quad (5)$$

In which: m: mass of sample (g), m_1: mass of dry filter paper (g), m_2: mass of filter paper after drying containing insoluble powder (g).

Moisture: According to AOAC, 2007 for food, the gravimetric method is used to determine the moisture content of flour. The percentage loss in mass is obtained after drying 2.5 g at 105°C until constant mass and moisture content (%) are calculated [21]. Using Sartorius infrared moisture balance – Model: MA150 (Germany), weigh about 0.250g of powder, then spread the sample evenly on a silver plate before measuring moisture, each sample is measured 3 times.

Color characteristics: Using Konica Minolta food colorimeter (Japan), color parameters were determined by CIE L*a*b* system for the obtained powder [20]. The powder is contained in a specialized dark container, the results after measurement are displayed on the colorimeter, each sample is repeated 3 times.

Particle size distribution: Particle size distribution was measured using a Mastersizer 2000 (Malvern Instruments Ltd., Malvern, UK) using laser diffraction. Isopropanol was used as a dispersant [22].

2.6 Determination of total polyphenol content (TPC)

Total polyphenol content was determined by UV-VIS method with Folin – Ciocalteu reagent and measured spectrophotometrically at 734 nm wavelength [23]. TPC content was calculated as a percentage of dry sample mass, according to the formula:

$$TPC = \frac{(D_{sample} - D_{intersection}) \times V_{sample} \times 100}{S_{standard} \times m_{sample} \times 10000 \times W_{DM,sample}} \quad (6)$$

In which: D_{sample}: optical density obtained for the test sample solution; $D_{intersection}$: optical density at the point where the best-fit linear calibration curve intersects the y-axis; $S_{standard}$: is the slope obtained from the best-fit linear calibration; m_{sample}: mass of the test sample, in grams (g); V_{sample}: volume of the sample extract, in milliliters (mL); d: is the dilution factor used before determining the colorimetric measurement; $W_{DM,sample}$: is the dry matter content of the test sample, in mass percentage (%).

2.7 Determination of total flavonoids content (TFC)

Flavonoid content was determined by UV-Vis method with aluminum chloride reagent and measured spectrophotometrically at 510 nm wavelength [24]. TFC was calculated by the formula:

$$TFC = \frac{C_x \times V_{norm} \times K}{C \times a \times (100 - W)} \quad (7)$$

In which: C_x: Total flavonoids content in the extract calculated from the standard curve (mg/mL); a: mass of sample soaked in extract (g); C: ppm conversion value ($C = 10^3$); V_{norm}: volume of extract after titration (mL); K: dilution factor (if any); W: sample moisture (%).

2.8 Determination of betacyanin content (BC)

The method of Betacyanins analysis was based on the method of [25]. Pipette 2ml of sample diluted with Mcllvaine buffer solution (pH=6.5) in a volumetric flask and measure the spectrophotometer at 538nm. The total betacyanins content was calculated by the formula:

$$BC = \frac{A \times DF \times V \times MW \times 100}{\varepsilon \times L \times M} \quad (8)$$

In which: A: absorbance value at Amax (538nm); DF: dilution factor; V: volume of extract; MW: molecular weight of betanin (550 g/mol); ε: molar coefficient of betanin (60000 L/mol.cm); L: path length of cuvette (1cm); M: mass of dry sample (g)

2.9 Accelerated Storage Stability

The extracts and spray-dried powders from red dragon fruit were placed in PP bags (100 × 60 mm) and stored at 50±1°C with RH 55-60% for 5 weeks. The stability was assessed every 7 days by quantifying TPC, TFC and betacyanin.

2.10 Statistical analysis

Analysis of variance (ANOVA) was applied at a 95% confidence level (*p-value* < 0.05) to assess the differences between samples. Furthermore, a correlation analysis between all studied parameters, at a 95% significance level, was conducted using Statgraphics data processing software.

3. RESULT AND DISCUSSION

3.1 Product yield, drying rate, spray drying capacity

Table 1: Result of product yield, drying rate, spray drying capacity

Brix 15	Product yield (PY %)	57.01
	Drying rate (DR %)	88.51
	Spray drying capacity (kg/h)	0.04
Brix 20	Product yield (PY %)	65.21
	Drying rate (DR %)	86.96
	Spray drying capacity (kg/h)	0.04

Table 1 displays the product yield (HP%), drying ratio (DR%), and spray drying capacity (kg/h) data for spray-dried powder using Maltodextrin as a drying aid at 160°C. The results showed that raising the concentration of drying aid (from Brix 15 to 20) boosted product yield significantly while decreasing drying ratio and capacity. The product yield increased by approximately 8.205% (from 57 to 65.205%), whereas the drying ratio and drying capacity reduced slightly with two carrier concentrations (drying ratio decreased from 88.51 to 86.959%, spray drying capacity decreased from 0.040 to 0.037 kg/h). Maltodextrin was chosen for this investigation since several earlier research findings demonstrated that it is an optimal carrier for the spray drying procedure [26]. Several other research have also demonstrated that maltodextrin boosts product yield [20,27]. Adhesion can be reduced by using high doses of high molecular weight compounds. Several studies have also shown that increasing the maltodextrin content improves solids recovery following spray drying [12].

From Table 1, the concentration of dry matter in Brix 15 is lower than that in Brix 20, resulting in less powder obtained after spray drying, reducing the product recovery efficiency. Brix 15 has a lower viscosity than Brix 20, so during the drying process, the amount of water evaporated is lower and the ability to form granules is easier, leading to higher drying rates and productivity. According to the study of Ismail Tontul et al., the glass transition is higher when the carrier content is higher because higher viscosity will affect the drying process efficiency. Therefore, after spraying, the drying material droplets collide less with the drying surface at high speed and intensity, creating less sediment on the drying surface and increasing the efficiency of the spray drying process [28]. According to the study of Renata et al., high maltodextrin concentration has a negative impact on the process productivity, possibly due to the viscosity of the mixture, which increases exponentially with this variable. Increased viscosity of the fluid can cause more solids to stick to the main chamber wall, thus reducing the process yield. In addition, the higher the solid content of the mixture, the more solids can come into contact with the chamber wall and stick to it. Therefore, the process yield is lower [13].

3.2 Physical properties

Table 2: Result of physical properties

	Brix 15	Brix 20
Water absorption index (WAI %)	11.01 ± 0.15[a]	34.15 ± 0.07[b]
Water solubility index (WSI %)	93.09 ± 0.09[a]	90.24 ± 0.13[b]
Particle size (μm)	3.60 ± 0.73[a]	4.80 ± 0.97[b]
Moisture (%)	5.28 ± 0.03[a]	3.19 ± 0.01[b]
$L*$	32.73 ± 0.78[a]	33.79 ± 1.66[b]
$a*$	8.96 ± 0.20[a]	8.25 ± 0.36[b]
$b*$	-1.00 ± 0.10[a]	-1.71 ± 0.06[b]

**Data were expressed as Mean ± SD of three experiments, and different lowercase letters indicated statistically significant differences among the treatments (p-value < 0.05)*

Water absorption index (WAI %) and water solubility index (WSI %)

WSI and WAI are shown in Table 2. The results show that the water absorption index increases more than 3 times when the Brix of the drying material increases from 15 to 20 (increasing from 11.009 ± 0.153 to 34.146 ± 0.073%). However, the water solubility index decreases when the soluble content in the drying material increases (from 93.092 ± 0.095 to 90.224 ± 0.133%). These are two relatively important indicators in the storage and preservation of powdered preparations, closely related to the water retention and water solubility of powdered products. Where WAI indicates the fixed water content of the sample [29], and WSI is connected to the number of soluble solids included in the product as a function of starch, sugar, protein, fiber, and maltodextrin solubilities. The water content of a powder product is connected to its free-flowing qualities and stability during storage because it influences the glass transition and crystallization behavior [30]. García-Segovia et al. found that increasing the concentration of drying aids gradually raises the fixed water content while decreasing the solubility of solids in the product [20]. The addition of low-viscosity maltodextrin at high solids ratio, high glass transition temperature and low hygroscopicity as a carrier can reduce the hygroscopicity of betacyanin powder [31]. The addition of maltodextrin concentration can increase the number of soluble solids and reduce the amount of water evaporated [32].

Moisture

The results of the moisture content of dragon fruit powder at 2 degrees Brix 15 and 20 after drying are shown in Table 2, showing that the moisture content decreased significantly as the Brix increased; at Brix 15, the moisture content was 5.277 ± 0.025%, significantly higher than that at Brix 20 which was 3.193 ± 0.035% and there was a significant difference (p-value < 0.05). The moisture content was significantly affected by the concentration of maltodextrin, the total soluble solids content of the extract increased with increasing maltodextrin content and for this reason, the amount of water needed to evaporate decreased. Therefore, the remaining moisture in the powder decreased. According to the study of Bakar et al. on spray-dried powder from red dragon fruit peel extract [33] and the study of Caliskan et al. on spray-dried powder from sumac extract [34], it was shown that the moisture content of the powder had an inverse relationship with the increasing concentration of maltodextrin. The addition of maltodextrin to the material before spray drying increased the total solid content of the material and thus reduced the amount of free water that could be evaporated.

Color characters

The measurement results from Table 2 show that the L* value (brightness) of Brix 15 powder is 32.73 ± 0.78, lower than Brix 20 which is 33.79 ± 1.66, the a* value (redness) of Brix 15 powder is 8.96 ± 0.20, higher than Brix 20 which is 8.25 ± 0.36, the b* value (blueness) of Brix 15 powder is -1.00 ± 0.10, while Brix 20 decreases to -1.71 ± 0.06, and these values are all different according to the Brix degree of the powder (p-value < 0.05). The color values show that Brix 20 powder has less red shade, but the color of the powder is brighter, with more blue shades. In general, the color values (L*, a* and b*) of spray-dried powders were significantly affected by maltodextrin concentration (p-value < 0.05), as the MD concentration increased, the L* value increased but a* and b* values decreased. Maltodextrin and temperature have a substantial effect on the color characteristics of powders. Mishra et al. found that maltodextrin concentration had a substantial impact on the brightness of powders produced at input temperatures below 200°C. Higher quantities of maltodextrin and higher inlet temperatures resulted in lower a/b values [35]. At the same time, Tran et al. discovered that all spray-dried dragon fruit powder samples had nearly the same light purple-red color, with color intensity decreasing as the maltodextrin concentration climbed from 10% to 20%. This can be explained by the influence of the white color of maltodextrin on the color of the samples; the higher the concentration of maltodextrin, the lighter the colour of the powder samples [36].

Powder particle size

The data from Table 2 demonstrate that the particle size rises with increasing Brix. At Brix 15, the particle size is 3.6 ± 0.73 µm, while at Brix 20, it is 4.8 ± 0.97 µm. The particle size is different at 2 Brix degrees (p-value < 0.05). Maltodextrin content influences average particle diameter as well. The particle size of the powder increases as the concentration of maltodextrin is increased from 15 to 20%. The results are comparable to the study of Ferrari et al. (2011), where the particle size of the powder increases with increasing carrier concentration [16]. According to Goula and Adamopoulos [37], the size of spray-dried particles depends on the size of the spray droplets, which is affected by the type of sprayer, the physical properties of the feed solution and the concentration of the solids fed. Higher concentrations of maltodextrin also resulted in larger particles, which may be related to the viscosity of the feedstock, which increased exponentially with the concentration of maltodextrin. Larger droplets were formed during spraying as the viscosity of the feed solution increased, resulting in larger particles. This is consistent with the results obtained for acai berry hydrolysate, prickly pear juice, and chicken meat produced by spray drying.

According to Masters (1991), the average liquid droplet size varied directly with the viscosity of the liquid at a constant spray rate [38]. The higher the liquid viscosity, the larger the droplets formed during spraying and, therefore, the larger the particles obtained by spray drying. This is consistent with the results published by Jinapong et al. (2008), for instant soymilk powder produced by ultrafiltration and spray drying in a rotary atomizer [39]. Keogh et al. (2003) observed a linear increase in particle size with feed viscosity, when studying spray drying of ultrafiltered concentrated whole milk in a twin-nozzle fluid sprayer [40]. In both works, the authors attributed the increase in particle size to an increase in feed viscosity.

3.3 Total polyphenol content (TPC), total flavonoid content (TFC) and betacyanin content

Table 3: TPC, TFC, Betacyanin content of spray-dried dragon fruit powder

Sample	Contents		
	TPC (mgGAE/g)	TFC (mgQAE/g)	BC (mg/100g)
Brix 15	0.79 ± 0.01[a]	0.17 ± 0.01[a]	44.95 ± 0.46[a]
Brix 20	0.62 ± 0.02[b]	0.12 ± 0.02[b]	45.44 ± 0.83[a]

**Different letters in the same column show significant differences ($p \leq 0.05$)*

Food processing, especially thermal processing, can cause nutrient losses in food products, making the food industry face a major challenge of preserving functional components during processing [41]. Therefore, retaining bioactive compounds during processing is of great concern.

The phenolics, flavonoids, and betacyanin contents of dragon fruit varied with different amounts of added maltodextrin. The TPC content of dragon fruit powder at Brix 15 (0.79 ± 0.012 mg GAE/g) was higher than that at Brix 20 (0.62 ± 0.016 mg GAE/g). TFC and betacyanin contents also followed a similar trend, with Brix 15 (0.17 ± 0.01 mg QAE/g, 5.27 ± 0.20 mg/g) being higher than Brix 20 (0.12 ± 0.02 mg QAE/g, 3.21 ± 0.48 mg/g). This reduction in bioactive compounds at Brix 20 could be attributed to the dilution effect of maltodextrin, which increases the total solids content, thereby reducing the relative concentration of polyphenols and flavonoids. Furthermore, the higher viscosity of the Brix 20 solution may have reduced the efficiency of microencapsulation, exposing bioactive compounds to oxidative degradation. The results showed that the amount of maltodextrin added to the dragon fruit extract had a significant effect on the color and compounds present in the dragon fruit extract, indicating that the addition of less maltodextrin was able to retain higher phenolics, flavonoids, and betacyanin compounds. Silva et al. study showed that the incorporation of maltodextrin resulted in a decrease in the percentage of phenolics and flavonoids in the obtained pulp mass [42]. The study by Duong et al. showed that the betacyanin content of dried dragon fruit powder at 15% concentration was higher than that at 20% concentration due to the increased viscosity of the extract, which hindered the effective atomization process as well as reduced water evaporation for microcapsule production, thus, the rapid shell formation process to protect the core was less effective [43]. The TPC of the powders ranged from 0.62 to 0.79 GAE mg/g, and the TPC recovery in powders with different wall materials increased at different levels, from 22 to 36%. These results are consistent with a previous study on the recovery of phenolic content in juices (from orange, watermelon, star fruit, and pineapple) coated with 20% MD by spray drying. However, in contrast to Silva et al. (2024), who reported increased polyphenol retention at higher maltodextrin concentrations, our findings suggest that excessive maltodextrin may hinder effective encapsulation. This discrepancy could be due to differences in drying conditions and feed composition, highlighting the need for further research on the role of maltodextrin in polyphenol preservation [44]. The above study showed that TPC in orange powder increased 4-fold after spray drying, while the other three fruit powders contained similar or decreased TPC. This indicates that the change in TPC during spray drying may be related to the juice types, as different fruits may have different phenolic profiles.

3.4 Effect of temperature on the retention of natural compounds in dragon fruit

Total polyphenol content (TPC)

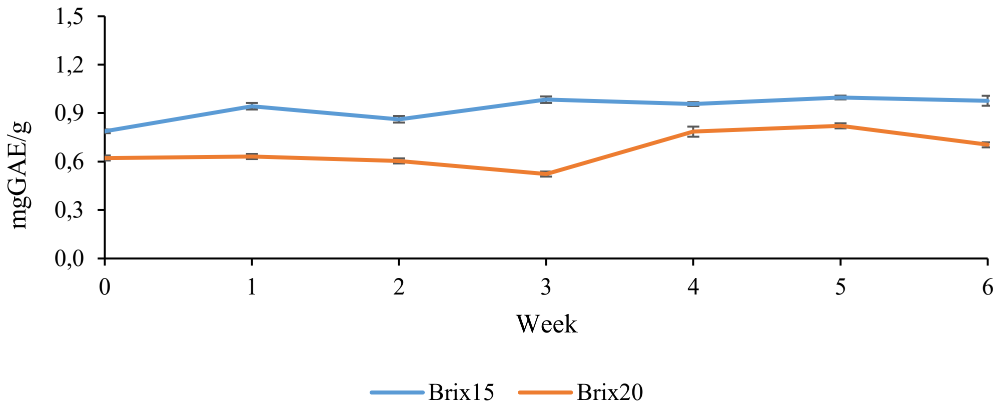

Figure 1: TPC content of 2 types of dragon fruit powder stored at 50°C.

The change of TPC in spray-dried dragon fruit powder samples stored at 50°C for 6 weeks is shown in Figure 1. In general, all powder samples showed wavy patterns instead of a linear degradation trend over storage time. TPC content of 2 types of dragon fruit powder when stored at 50°C tended to increase, and Brix 15 dragon fruit powder was more stable than Brix 20. The change of powder samples between days during storage did not differ (p-value > 0.05), but there was a difference between the 2 brix degrees (p-value < 0.05), TPC tended to decrease as the concentration of maltodextin increased. Storage temperature had an effect between different phenolic compounds. In general, elevated storage temperatures (45–50°C) can accelerate degradation processes, particularly oxidative reactions affecting bioactive compounds. However, phenolic stability is also influenced by structural transformations over time. Previous studies, including Zhang et al. [45], have shown that phenolic content may fluctuate during storage, sometimes peaking due to polymer breakdown into smaller, more extractable phenolics. Additionally, their findings indicate that storage at 25°C over extended periods can maintain phenolic stability, challenging the assumption that lower temperatures always provide superior protection. These insights suggest that phenolic stability depends on both temperature and molecular transformations, rather than temperature alone. Protocatechuic acid and quercetin both showed a slight increase after storage. These results suggest that higher temperature (45°C) may facilitate the release of protocatechuic acid and quercetin. Quercetin may be produced from the hydrolysis of quercetin glycoside, as increased quercetin yield from quercetin-3-O-rutinoside was reported with increasing extraction temperature [46].

In this study, the phenolic compounds under study increased at different levels. A similar phenomenon was also observed by Flores et al., who reported a 2- to 2.5-fold improvement in TPC in spray-dried blueberry pomace extracts after 40 days of storage. They concluded that TPC may be preserved due to some new phenolic compounds being produced during storage [47]. Similarly, Tsali and Goula (2018) also found an increase in phenolic retention in encapsulated grape pomace during storage, which they suggested could be due to the hydrolysis of conjugated polyphenols [48]. During storage, the phenolic profile may change as some compounds may degrade while other new phenolic compounds may be formed. This may increase TPC and compensate for the loss of antioxidant compounds from degraded compounds. The chemical configuration changes in phenolic compounds during spray drying may also make them more soluble and extractable in water during the Folin-Ciocalteau test, resulting in an increase in TPC [44]. In addition, it has been reported that heat treatment can lead to the cleavage of phenolic-sugar glycosidic bonds, generating phenolic aglycones and improving the reactivity with the Folin-Ciocalteau reagent [49]. This would increase the TPC obtained.

Total flavonoid content (TFC)

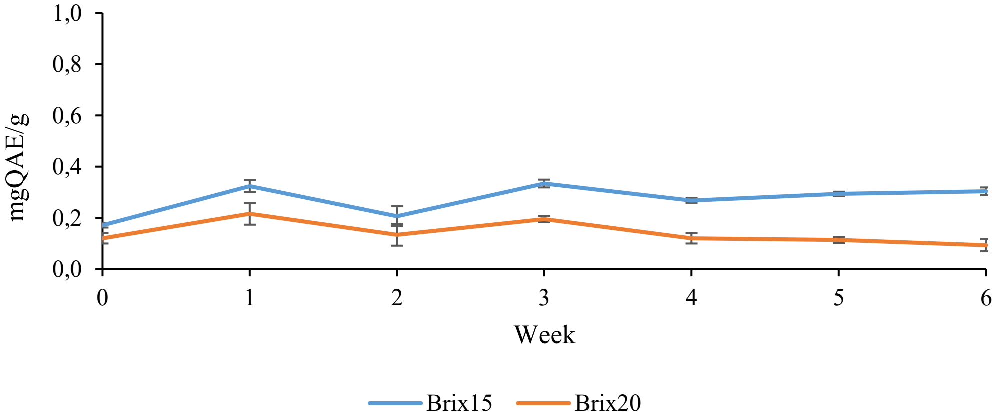

Figure 2: TFC content of 2 types of dragon fruit powder stored at 50°C.

The TFC content of 2 types of dragon fruit powder when stored at 50°C tended to increase slightly and remained stable, the change of powder samples between days during storage was different (*p-value* < 0.05) and there was a statistically significant difference between the 2 powder samples (*p-value* < 0.05). According to the study of Alena Stupar et al., spray-dried garlic powder (with added maltodextrin) stored for 3 months at room temperature, the change in TFC content tended to decrease gradually but was quite stable [50]. In a study by Phanita Vonghirundecha et al. [51], the TFC content of spray-dried Moringa oleifera leaf powder (with maltodextrin added) at 37°C for 90 days varied but remained stable. The study evaluated the effect of maltodextrin concentration on the stability of total flavonoid content in spray-dried dragon fruit powder. Interestingly, Brix 15 maltodextrin dragon fruit powder had a higher initial total flavonoid content, and both exhibited thermal stability after storage. This unexpected result suggests that lower maltodextrin concentrations may better protect flavonoids during drying and storage. Although the exact mechanism behind this phenomenon needs further investigation, it is possible that lower maltodextrin concentrations may result in smaller particle size and denser matrix in spray-dried powder [52]. Additionally, the lower sugar content in the Brix 15 formulation may have reduced the Maillard reaction, a non-enzymatic browning reaction that can degrade bioactive compounds [44]. However, it is important to note that the overall stability of both formulations was relatively high, with minimal loss of flavonoids after 5 weeks of storage at 50°C. This suggests that spray drying is an effective method and an appropriate carrier concentration for preserving bioactive compounds in dragon fruit.

Betacyanin content (BC)

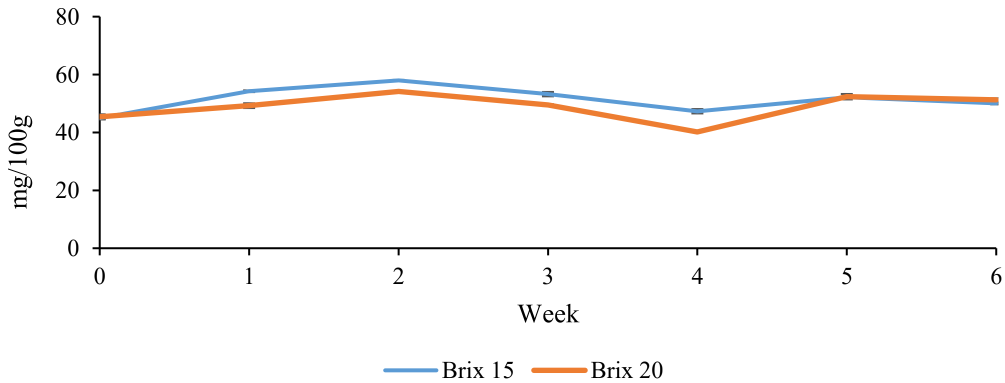

Figure 3: Betacyanin content of 2 types of dragon fruit powder stored at 50°C.

The betacyanin content of 2 types of dragon fruit powder when stored at 50°C tended to decrease. The change of powder samples between days during storage and between 2 powder samples were different (*p-value* < 0.05). The results in the study were like the study of Ee, S. C. et al., red dragon fruit powder after spray drying stored at 45 ± 2°C decreased slightly but was stable for 14 weeks of storage [53]. The study of Duong Thi Ngoc Diep et al. also showed that when storing dragon fruit powder at 50°C, betacyanin compounds in the powder changed due to temperature, but were stable for 30 days [54]. The higher the concentration of maltodextrin added with the same DE, the lower the betalain recovery [55]. The results also showed the same thing, when increasing the concentration of maltodextrin, the betacyanin content decreased.

4. CONCLUSION

This study highlights the trade-off between yield and bioactive compound retention in spray-dried red-fleshed dragon fruit powder when varying maltodextrin concentration. Increasing maltodextrin content from Brix 15 to Brix 20 enhanced product yield (from 57.01% to 65.21%) and improved powder properties such as lower moisture content, higher water absorption index, and increased particle size. However, a higher maltodextrin concentration resulted in lower retention of total polyphenols (TPC), total flavonoids (TFC), and betacyanin, indicating a dilution effect and potential degradation of bioactive compounds during processing. Storage stability analysis at 50°C revealed that both formulations maintained bioactive compounds over six weeks, but Brix 15 powder exhibited superior stability, particularly in TPC and TFC retention. While betacyanin content showed slight degradation, it remained relatively stable in both samples. These findings suggest that lower maltodextrin concentrations may provide better protection for bioactive compounds, while higher concentrations improve process efficiency.

Further research is recommended to elucidate the protective mechanisms of maltodextrin, particularly its role in stabilizing bioactive compounds during drying and storage. Specifically, studies should investigate the effects of different maltodextrin DE values on bioactive compound retention, as well as the potential of alternative encapsulating agents such as gum arabic and inulin. Additionally, real-time storage studies at refrigeration and ambient temperatures should be conducted to better simulate commercial conditions. Additionally, exploring alternative maltodextrin types, lower storage temperatures, and complementary encapsulating agents could optimize both yield and compound retention. The developed spray-dried dragon fruit powder demonstrates potential applications in functional foods, beverages, and natural food colorants. Its high antioxidant content and stability make it a promising ingredient for health-focused products, with further studies needed to refine processing parameters for enhanced commercial viability.

CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the publication of this article.

ACKNOWLEDGEMENTS

This research was funded by the Scientific Research Fund of Ho Chi Minh City University of Industry (IUH), project code 23.1 SHTP02, under contract number 161/HĐ-ĐHCN dated November 7, 2023.

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ĐẶC TÍNH KỸ THUẬT VÀ KHẢ NĂNG BẢO QUẢN CỦA BỘT THANH LONG RUỘT ĐỎ (HYLOCEREUS COSTARICENSIS) SẤY PHUN

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Tóm tắt: Thanh long ruột đỏ (Hylocereus costaricensis) là một loại trái cây nhiệt đới giàu chất chống oxy hóa và hợp chất hoạt tính sinh học nhưng dễ hỏng. Nghiên cứu này đã điều tra ảnh hưởng của maltodextrin (DE 11.9) ở nồng độ Brix 15 và Brix 20 đến hiệu suất thu hồi, đặc tính vật lý, hàm lượng hợp chất hoạt tính sinh học và độ ổn định bảo quản của bột thanh long sấy phun. Kết quả cho thấy việc tăng nồng độ maltodextrin từ Brix 15 lên Brix 20 cải thiện đáng kể hiệu suất sản phẩm (từ 57,01% lên 65,21%) nhưng làm giảm tốc độ sấy và năng suất sấy phun. Các đặc tính vật lý cũng bị ảnh hưởng, với mức maltodextrin cao hơn dẫn đến tăng chỉ số hấp thụ nước (từ 11,01% lên 34,15%), giảm chỉ số hòa tan trong nước (từ 93,09% xuống 90,24%), kích thước hạt lớn hơn và màu sắc sáng hơn. Tuy nhiên, việc giữ lại tổng polyphenol (TPC), tổng flavonoid (TFC) và betacyanin cao hơn ở bột Brix 15. Các thử nghiệm độ ổn định ở 50°C cho thấy cả hai công thức đều duy trì tốt hàm lượng hợp chất hoạt tính sinh học trong sáu tuần, nhưng bột Brix 15 ổn định hơn, đặc biệt về hàm lượng TPC và TFC. Những kết quả này nhấn mạnh tiềm năng ứng dụng của bột thanh long sấy phun như một thành phần thực phẩm chức năng, với Brix 15 giữ lại chất hoạt tính sinh học tốt hơn, trong khi Brix 20 nâng cao hiệu quả quá trình.

Từ khóa: betacyanin, đặc tính vật lý, polyphenol, thanh long ruột đỏ, sấy phun, độ ổn định.

Ngày nhận bài: 05/01/2025
Ngày nhận đăng: 28/3/2025