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Optimizing the foam-mat drying of red dragon fruit: Effect of drying temperatures and foaming agents

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Abstract

Foam-mat drying is an economical method compared to other drying methods commonly used today, especially convenient for products with high viscosity and difficult to dry in food powder production. In this study, the red-flesh dragon fruit foam drying study was arranged according to the Box-Behnken design with 18 treatments and 6 center point replications. The input variables were egg albumin (EA) at varying concentrations of 5, 10 and 15%, and glycerol monostearate (GMS) at varying concentrations of 1, 3 and 5%. The drying process is arranged at temperatures of 50, 60 and 70ºC. The dependent variables included in this study were betacyanin content (mg/100 g) and drying rate (g water/g dry matter/min). Response surface methodology was used to optimize the drying rate (g water/g dry matter/min) and betacyanin content (mg/100 g). Accordingly, the optimal conditions were found with concentrations of EA, GMS used and drying temperature of 10.43%, 2.97% and 63.21ºC respectively. These conditions created foam-dried red flesh dragon fruit powder containing optimal content of betacyanin is 54.33 mg/100 g at the optimal drying rate of 1.78 g water/g dry matter/min. Foam-mat dried red dragon fruit powder has beautiful color, low moisture content (≈8%) with the water solubility index (41.05%), water absorption index (3.5%) and hygroscopicity (20.11%) were determined.

Keywords: Red dragon fruit, Foaming agents, Foam mat drying, Betacyanin, Drying rate

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1. Introduction

Red-fleshed dragon fruit (*Hylocereus polyrhizus*) is grown in many parts of the world such as Southeast Asia, China, Bangladesh, Australia and Israel, although this fruit is not native to those regions [1]. The fruit flesh is delicious, succulent and contains many small black seeds [2]. The red dragon fruit had highly bioactive compounds such as vitamin C, fiber and polyphenols [3]. Dragon fruit is also an important source of water-soluble betalain compounds. Betalains are natural pigments that include purple red betacyanin and yellow betaxanthin. Besides its coloring properties, betacyanin also exhibits antioxidant activity [4]. Kaur and Kapoor [5] reported that betacyanin can prevent oxidative processes that contribute to several degenerative diseases in humans. Betacyanin is also the main coloring compound of dragon fruit, this is also a potential source used as a beautiful, natural red pink colorant in food processing [6]. However, the red dragon fruit is very perishable after harvest, so appropriate research is needed to protect natural color compounds with high antioxidant activity in the fruit [7]. Creating vibrant food colors is also the work of this research. Food color is one of the factors that strongly affects sensory value, especially appeal to consumers. In recent years, consumers have become increasingly concerned about the safety of synthetic colorants. Industrial production of natural colors is receiving more attention [8].

To create pigment from red-flesh dragon fruit, the foam-mat drying method was chosen for this study. This is a technique that involves incorporating a foaming agent into a liquid/semi-liquid with appropriate whipping to form a stiff and stable foam, followed by dehydration with hot air [9]. The foam-mat drying method is relatively simple with the advantage of dehydration at low drying temperatures in a short time, easily applied to products with high sugar content and high viscosity [10]. The foaming method also increases the surface area, facilitating increased drying rate and significantly reducing drying time and temperature. Short drying times not only reduce dryer load but also increase dryer capacity by 32% and 22% for porous materials [11]. Materials that are less affected by temperature will improve sensory, nutritional and functional properties and protect the product from the effects of chemical, biochemical and even microbial reactions. Currently, research into producing powder from red-flesh dragon fruit using foam drying technology is still limited. Meanwhile, as more information about the side effects of artificial colors continues to spread worldwide, natural colors are gradually taking an important position in food processing. Food manufacturers always tend to find ways to replace synthetic colorants with natural color products. Therefore, studying the effects of foam drying technique on the quality of red-fleshed dragon fruit powder is of interest in order to create high-quality powder products that meet consumer needs for nutritional value, sensory value as well as health effect. This activity also helps increase the economic value of fruits and vegetables grown in Vietnam.

2. Materials and methods

2.1 Sample selection and preparation

Red-flesh dragon fruit was purchased at the local dragon fruit garden. The fruits were washed, peeled, chopped and frozen at -25ºC. Some analyzes were performed on fresh raw materials after peeling: moisture content: 85.92±0.35%, betacyanin content 41.76±0.05 mg/100 g. The measured L*, a*, b* in color values were to be 34.84±1.83, 22.86±1.24, -2.27±0.15, respectively. When used, the red-fleshed dragon fruit was weighed to a determined weight, distilled water was added according to the fruit flesh: water ratio of 83.74:16.26 (% v/v). The extraction process was performed in an ultrasonic bath (Brason, 450W, 42 kHz, USA) for 13.15 minutes [12]. After extraction, the sample was filtered to remove particles and recover the extract. The extract was stored at -25ºC for use in the following experiments.

2.2 Box–Behnken Design

The Box-Behnken design (BBD) of response surface methodology (RSM) with three levels was used for this study. The optimized process is arranged according to three input variables including X_1 (egg albumin 5, 10, 15%), X_2 (glycerol monostearate 1, 3, 5%) and X_3 (drying temperature 50, 60 and 70ºC). The selected responses were drying rate (Y_1) and betacyanin (Y_2) with the coded levels were given in Table 1. Eighteen runs were performed to select the best combination of input variables (Table 2) to produce the appropriate drying rate for the red-fleshed dragon fruit powder to maintain the highest betacyanin content. All responses were analyzed in triplicate and the mean was reported.

Table 1: Experimental ranges and levels of independent variables

Factors	Unit	Symbol	Ranges and levels		
			Low (–1)	Intermediate (0)	High (+1)
Egg albumin	%	X_1	5	10	15
Glycerol monostearate	%	X_2	1	3	5
Drying temperature	ºC	X_3	50	60	70

Table 2: Experimental conditions based on BBD

No.	EA (%)	GMS (%)	Drying temperature (ºC)	No.	EA (%)	GMS (%)	Drying temperature (ºC)
1	10	3	60	10	15	5	60
2	5	3	50	11	10	1	50
3	10	3	60	12	15	3	50
4	5	1	60	13	10	1	70
5	10	5	50	14	10	5	70
6	10	3	60	15	10	3	60
7	10	3	60	16	10	3	60
8	15	3	70	17	5	3	70
9	15	1	60	18	5	5	60

The second-order polynomial regression equation (equation 1) was often applied to fit experimental data and model the responses.

$$Y = \alpha_o + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_{12} X_1 X_2 + \alpha_{13} X_1 X_3 + \alpha_{23} X_2 X_3 + \alpha_{11} X_1^2 + \alpha_{22} X_2^2 + \alpha_{33} X_3^2 \quad (1)$$

where: Y is predicted responses (drying rate, betacyanin); α_o is intercept coefficient; α_1, α_2, α_3 are linear terms; α_{11}, α_{22}, α_{33} are quadratic terms; α_{12}, α_{13}, α_{23} are interaction terms and X_1, X_2, X_3 are independent variables.

2.3 Foam-mat drying

Fix the volume of each experimental batch to 100 mL, then weigh the EA and GMS with the ratios as arranged and put them into a 500 mL beaker. Whipping for 5.8 minutes to create foam with a mixer (Philips HR 3705-300 W, Columbus, OH, USA) at highest speed [13]. After being whipped, the mixture is spread on a stainless-steel tray (lined with parchment paper) with a foam thickness of 3 mm, then dried at temperatures of 50, 60 and 70ºC in a drying oven (MEMMERT, UN260, Germany) with a wind speed of 1.0

m/s. The sample was dried until the moisture content reached equilibrium (the moisture was about 8%). Then, the powder is finely ground to a size of about 0.04 mm. The collected samples have been analyzed for necessary criteria.

2.4 Physico-chemical properties analysis

The moisture content of the sample was determined according to the AOAC standard method [14]. Water activity (a_w) was measured using a RotronicHygroPalm HP23-AW-A-SET-40 measuring instrument (USA). The color values (L*, a* and b*) of red dragon fruit powder were measured using a Hunter Lab Colorimeter (Color Flex, USA). Betacyanin content was analyzed according to the method of Wybraniec and Mizrahi [15].

2.5 Drying rate calculation

Drying rate was calculated according to the formula presented in the publication of Thuy *et al.* [16].

2.6 Water solubility index, water absorption index, and hygroscopicity

The water solubility index (WSI) and water absorption index (WAI) were calculated according to Grabowski *et al.* [17]. Hygroscopicity was determined according to the method proposed by Aslan and Ertaş [18].

2.7 Statistical analysis

Regression analysis and analysis of variance (ANOVA) were used to fit the models (represented by Equation 1) and test the statistical significance of model terms. The adequacy of the models was determined using model analysis and coefficient of determination R^2 analysis. The F and P-values were used to test the significance of all fitted equations at the 5% significance level. To be able to determine the relationship between the responses (dependent variables) and the experimental levels of the independent variables and to deduce the optimal conditions, the fitting equations expressed as contours are created with Statgraphic Centurion software (version XV.I, USA).

3. Results and Discussions

3.1 Effect of foaming agent, foam stabilizer and drying temperature on drying rate and betacyanin content in red dragon fruit powder

Foam-mat drying of red dragon fruit used a combination of two foaming agents, EA and GMS at different concentrations and dried at predetermined temperatures. Analytical results showed that EA, GMS and drying temperature all affect drying rate and betacyanin content (**Table 3**).

Table 3: Effects of EA, GMS concentration and drying temperature (designed according to Box-Behnken) on drying rate and betacyanin

No.	EA (%)	GMS (%)	Drying temperature (ºC)	Drying time (hours)	Drying rate (g water/g dry matter/min)	Betacyanin content (mg/100 g)
1	10	3	60	4	1.65±0.05	55.84±1.58
2	5	3	50	9	0.85±0.05	41.55±2.42
3	10	3	60	4	1.64±0.04	56.10±1.28
4	5	1	60	5.5	1.37±0.10	50.85±2.09
5	10	5	50	7	0.95±0.09	43.36±1.70
6	10	3	60	4	1.62±0.03	56.98±0.89
7	10	3	60	4	1.63±0.03	56.67±0.40
8	15	3	70	2.5	2.20±0.05	34.62±0.61
9	15	1	60	3.5	1.64±0.03	44.07±0.89
10	15	5	60	3	1.75±0.02	41.66±1.52
11	10	1	50	7.5	0.92±0.06	44.24±1.65
12	15	3	50	5	1.17±0.02	37.39±1.23
13	10	1	70	4	1.87±0.06	41.41±1.59
14	10	5	70	3.5	1.90±0.06	41.25±2.24
15	10	3	60	4	1.63±0.04	56.14±1.89
16	10	3	60	4	1.64±0.06	56.17±1.30
17	5	3	70	4.5	1.69±0.02	40.11±2.41
18	5	5	60	5	1.40±0.11	49.14±1.65

Mean±STD

The drying rate value was highest (2.2 g water/g dry matter/min) when EA foaming agent used at 15% concentration and dried at 70ºC (short drying time, just 2.5 hours). Meanwhile, the drying rate value was lowest (0.85 g water/g dry matter/min) when using EA 5% and drying temperature 50ºC (longer drying time, about 9 hours). Thus, increasing EA concentration (from 5 to 15%) and drying temperature (from 50 to 70ºC) both significantly affect on drying rate. High concentrations of EA increased the penetration of air into the porous structure, thereby also increasing the drying rate and reducing drying time. Kadam and Balasubramanian [19] reported that the increase in foaming agent level enhanced the drying process (up to 15% egg albumin) and subsequently followed a decreasing trend with tomato juice.

GMS has little effect on drying rate; however, this agent also contributes to increasing drying rate (1.9 g water/g dry matter/min) when the highest GMS concentration used (5%) at drying temperature of 70ºC. When using a GMS concentration of 1 to 3%, the betacyanin content in the powder was well maintained with values between 44.33 and 48.39 mg/100 g, corresponding to the increased concentration. Similarly, albumin concentration and drying temperature also affected the betacyanin content in the product. When increasing the albumin concentration from 5 to 15% at temperatures 50 and 70ºC, the betacyanin content decreased (from 40.25 mg/100 g to 38.01 mg/100 g at 50ºC and from 38.77 mg/100 g to 34.62 mg/100 g at drying temperature of 70ºC). The highest betacyanin content was achieved at an albumin concentration of 10% at a drying temperature of 60ºC. However, when the temperature increased to 70ºC, the betacyanin content decreased, meaning the decomposition of betacyanin increased. This is probably because betacyanin is a temperature-sensitive pigment. When the temperature exceeds 60ºC, it can cause decomposition of this pigment [20]. In addition, betacyanin content decreased with increasing foaming albumin concentration, possibly due to dilution of betacyanin in the presence of this compound [21].

3.2 Effect of process parameters (EA, GMS, drying temperature) on drying rate

The results of variance analysis (ANOVA) for drying rate are presented in Table 4. The three independent variables EA (X_1), GMS (X_2), drying temperature (X_3) and other X_1X_3 interaction, squared interaction of X_2, X_3 all significantly affect drying rate (P-value<0.05) with high R^2 (97.98%) and low standard error of estimate (SEE = 0.053). However, the remaining interactions (X_1X_1, X_1X_2, X_2X_3) did not significantly affect drying rate (P-value>0.05). The coefficient of determination R^2 and the P-value of Lack-of-fit are 97.98% and 0.0937 (P-value>0.05), respectively, indicating a good fit of the experimental data.

Table 4: Analysis of variance for drying rate

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
X_1: EA (%)	0.781204	1	0.781204	277.44	0.0000
X_2: GMS (%)	0.0130667	1	0.0130667	4.64	0.0372
X_3: Drying temperature (ºC)	5.311	1	5.311	1886.20	0.0000
X_1X_1	0.00223131	1	0.00223131	0.79	**0.3786**
X_1X_2	0.00520833	1	0.00520833	1.85	**0.1812**
X_1X_3	0.0280333	1	0.0280333	9.96	0.0030
X_2X_2	0.088501	1	0.088501	31.43	0.0000
X_2X_3	0.0000083	1	0.00000833	0.00	**0.9569**
X_3X_3	0.274183	1	0.274183	97.38	0.0000
Lack-of-fit	0.0192583	3	0.00641944	2.28	0.0937
Pure error	0.115444	41	0.00281572		

The interactions that do not have a significant impact on drying rate are removed from the model, the regression equation showing the relationship between drying rate and independent variables is established (Equation 2) (R^2=97.87% and standard error of est.= 0.053).

$$Y_1 = -6.396 - 0.018X_1 + 0.117X_2 + 0.211X_3 + 0.001X_1X_3 - 0.021X_2^2 - 0.001X_3^2 \quad (\mathbf{2})$$

where: Y_1 is drying rate (g water/g dry matter/min), X_1 is EA (%), X_2 is GMS (%) and X_3 is drying temperature (ºC).

The response surface and contour plot (Figure 1) shows the impact of EA, GMS and drying temperature on drying rate. When fixing the drying temperature at 60ºC (Figure 1a), the drying rate increased from 1.22 to 1.65 g water/g dry matter/min when using EA content from 5% to 15%. However, when increasing the GMS content from 0 to 5%, the drying rate only has a small change (1.6 to 1.84 g water/g dry matter/min). EA is a protein that has the ability to create foam and stabilize foam when whipped, helping to create small air pockets and maintain the structure of the foam, thus increasing the foam expansion volume and stabilizing the foam [22]. Therefore, hot air can easily penetrate into the foam mass, resulting in increased drying rate and reduced drying time. Djaeni *et al.* [23] also reported that the higher albumin content, the faster drying rate.

Using GMS also reduces moisture faster, mixing GMS to tomato juice will form a foam-like structure, thus enabling to facilitate water vaporization [24]. When fixing the GMS concentration at 3% (Figure 1b), it was observed that drying temperature significantly affected the drying rate. When the drying temperature increased from 50 to 70ºC, the highest drying rate value (2.18 g water/g dry matter/min) was achieved when using 15% EA and performing the drying process at 70ºC. At a fixed concentration of 10% EA (Figure 1c), the calculated drying rate value is 1.96 g water/g dry matter/min, when using 3.3% GMS and drying at 70ºC. These obtained results are quite consistent with many findings reported in the literature for other food ingredients, in that higher temperatures increase the heat difference between drying air and foam, which can lead to higher drying rates [25-27]. Tekgül [28] also found that the drying rate of nectarine foam-mat powder increased as the drying temperature increased.

Response optimization was performed with the objective of maximizing drying rate with the optimal value achieved at 2.18 g water/g dry matter/min under optimal conditions of EA, GMS and drying temperature are 15%, 3.28% and 70ºC, respectively.

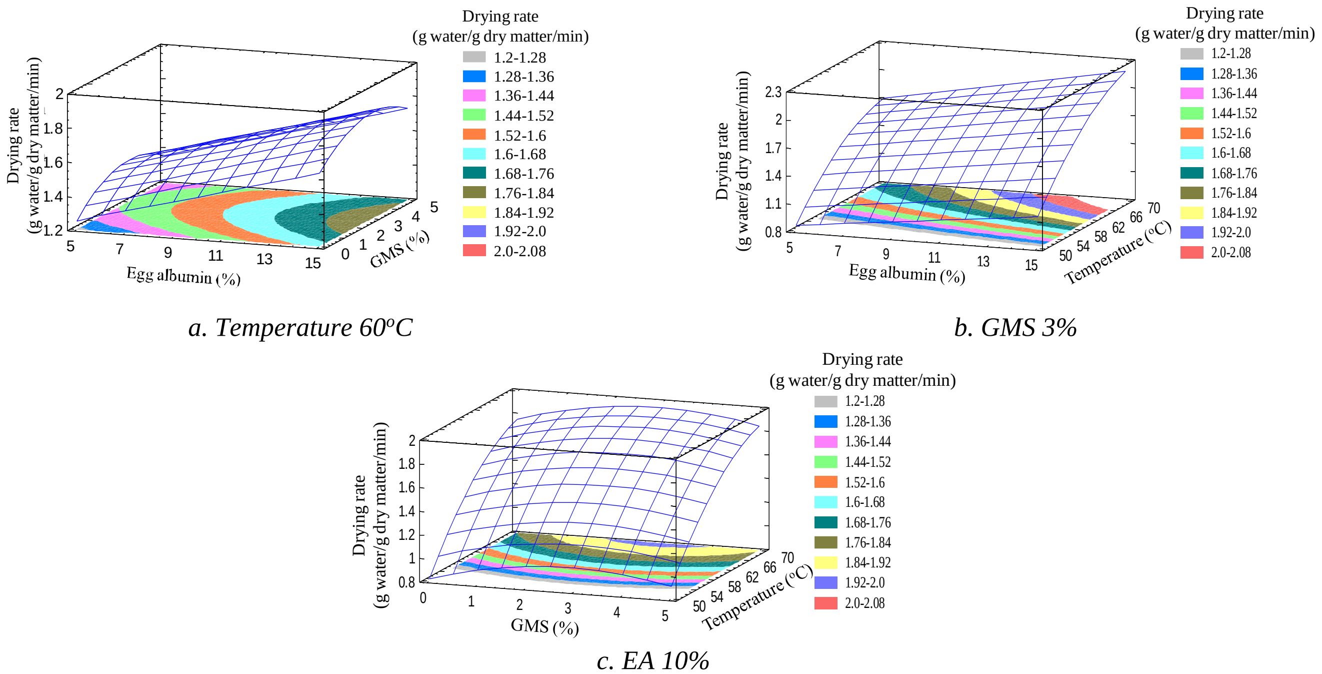


Figure 1: Response surface and contour plot of the influence of EA, GMS and drying temperature on drying rate

3.3 Effects of EA, GMS and drying temperature on betacyanin content

Optimization of betacyanin content was performed using RSM. The results of analysis of variance determined that the factors EA (X_1), GMS (X_2) and drying temperature (X_3) all affect betacyanin content (P-values<0.05) (Table 5).

Table 5: Analysis of variance for betacyanin content

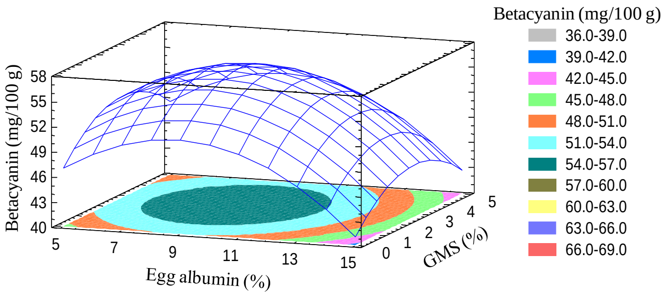
Source	**Sum of Squares**	**Df**	**Mean Square**	**F-Ratio**	**P-Value**
X_1: EA	214.443	1	214.443	90.57	0.0000
X_2: GMS	9.9975	1	9.9975	4.22	0.0463
X_3: Drying temperature	31.4875	1	31.4875	13.30	0.0007
X_1X_1	644.615	1	644.615	272.25	0.0000
X_1X_2	0.371008	1	0.371008	0.16	**0.6943**
X_1X_3	1.32667	1	1.32667	0.56	**0.4584**
X_2X_2	107.682	1	107.682	48.48	0.0000
X_2X_3	0.3888	1	0.3888	0.16	**0.6874**
X_3X_3	1550.5	1	1550.5	654.86	0.0000
Lack-of-fit	11.7073	3	3.90244	1.65	0.1913
Pure error	97.0755	41	2.36769		

The P-value of Lack-of-fit is greater than 0.05 (P-value=0.19), indicating good agreement between experimental data and model prediction data with high accuracy. The high values of R^2 (95.7%) and low value of SEE (1.5) from the model were determined. However, the interactions X_1X_2, X_1X_3 and X_2X_3 did not significantly affect betacyanin content (P<0.05), therefore, these interactions were extracted from the model and model fitted to the data was constructed (Equation 3) with a high coefficient of determination (R^2=96.37%) and low SEE (1.54).

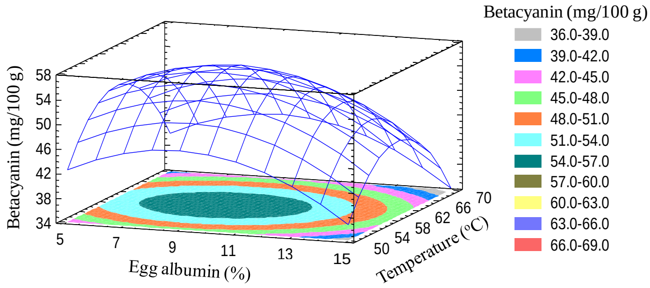
$$Y_2 = -356.18 + 5.02X_1 + 3.98X_2 + 12.95X_3 - 0.28X_1^2 - 0.72X_2^2 - 0.11X_3^2 \quad (3)$$

where: Y_2 is betacyanin content (mg/100 g), X_1 is EA (%), X_2 is GMS (%) and X_3 is drying temperature (°C).

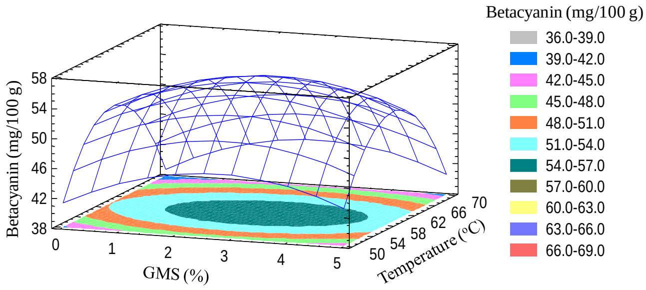
The response surface model showing the correlation between albumin concentration (%), GMS (%) and drying temperature (°C) for betacyanin content is presented in Figure 2. Based on the response surface graph and contour of each pair of factors showed that when fixing the drying temperature at 60°C (Figure 2a) and GMS at 3% (Figure 2b), the betacyanin content of the powder was well maintained when the albumin concentration increases. So higher concentrations of egg albumin help maintain and prevent the degradation of betacyanin. Some previous results reported that higher concentrations of egg albumin help maintain and prevent the rapid breakdown of betalains [29, 30]. However, when the albumin content exceeds the optimal point, the betacyanin content of the powder tends to balance or decrease slightly. Similarly, when the egg albumin content remained constant at 10% (Figure 2c), the betacyanin content of the powder had a high value when the GMS concentration increased from 1 to 2.78% and the drying temperature increased from 50 to 59.49°C. However, when it passes the optimal point, the betacyanin content tends to decrease. Analytical results showed that the betacyanin content varied from 34.62 mg/100 g to 56.69 mg/100 g, in which the lowest betacyanin content (34.62 mg/100 g) was found when the albumin and GMS concentrations were 15% and 3%, respectively, and the drying temperature of 70°C. In order to maximize betacyanin content at the optimum value 56.7 mg/100 g, the optimum of the input variables EA, GMS and drying temperature were determined as 8.93%, 2.77% and 59.47°C, respectively.



a. Drying temperature 60°C



b. GMS 3%



c. EA 10%

Figure 2: Response surface and contour plot of the influence of EA, GMS and drying temperature on betacyanin content

Mahayothee *et al.* [31] suggested that red-flesh dragon fruit slices can be dried at higher temperatures to shorten the drying time without significantly losing important bioactive compounds. Increased temperature will directly affect the stability of betalains [8]. Shorter drying times also improve betalain retention [30]. Pedreño and Escribano [32] also demonstrated that betalains are completely decomposed when subjected to temperature of 75°C.

3.4 Optimization and validation of experimental parameters

Simultaneous optimization of multiple response surfaces can reduce energy costs. From the obtained results, dependent variables such as drying rate and betacyanin content were individually optimized, so the optimal parameters of the independent variables (EA, GMS and drying temperature) were obtained with slightly different (EA from 8.9 to 15%, GMS from 2.77 to 3.28% and drying temperature 59.5 to 70°C). Therefore, optimizing the two responses (drying rate and betacyanin content) is more useful when it is necessary to evaluate the effects of multiple variables on these responses. Numerical optimization results showed that the desired maximum (0.76) can be achieved using the optimal values of EA, GMS and drying temperature of 10.43%, 2.97% and 63.2°C, respectively. Under these conditions, the optimal drying rate and betacyanin content were determined as 1.78 g water/g dry matter/min and 54.53 mg/100 g.

Testing the betacyanin content and drying rate from the optimal data of EA, GMS and drying temperature, the results showed that the betacyanin content and drying rate were close to the results predicted from the model. The difference is only about 1.89-2.08%, in which the betacyanin content is about 1.89%, lower than the predicted value and the drying rate is 2.08%, higher than the predicted value. All differences are less than 5% within the allowable range.

Red-flesh dragon fruit powder was processed under optimal conditions with a short drying time (2 hours 45 minutes) as shown in Figure 3. The product has a natural pink color, demonstrating the ability to maintain good betacyanin content. Gengatharan *et al.* [33] also suggested that betacyanin from red-fleshed dragon fruit has good color stability due to its low dehydrogenation rate, which can slowly change color from red to yellow pigment.

Figure 3: Foam-mat dried red flesh dragon fruit powder

Foam-mat dried red dragon fruit powder had low moisture and water activity, 7.89% and 0.45 respectively, capable of reducing biochemical reactions and preventing the growth of microorganisms, thus increasing the shelf life of the powder [34]. In addition, the water solubility index (WSI), water absorption index (WAI) and hygroscopicity in the product were also determined to be 41.05%, 3.5% and 20.11%, respectively. With these analysis results, dried red dragon fruit powder will be better used in processed products such as instant noodles, pasta, bread, and folk cakes.

4. Conclusions

From our research, the response surface method was effectively used to establish the optimal values of independent variables (EA, GMS and drying temperature) to increase drying efficiency (through high drying rate and short drying time) and best maintain betacyanin content, a bioactive compound in red-fleshed dragon fruit when processed into powder form. The obtained models are reliable, complete and accurate with a high coefficient of determination ($R^2 \geq 96\%$) indicating a reasonable fit of the developed quadratic polynomial regression model. With the optimal contents of EA, GMS and drying temperature respectively as 10.43%, 2.97% and 63.2ºC, the optimal drying rate and betacyanin content were determined as 1.78 g water/g dry matter/min and 54.53 mg/100 g, respectively. The results have also been verified. The data obtained from this study has confirmed that the foam-mat drying method is considered suitable for producing red-fleshed dragon fruit powder. This product can be used as food coloring or added to useful food product formulations on various industrial scales.

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