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Process of foam-mat drying of purple rice bran extract and evaluation of product properties

Proceso de secado en estera de espuma del extracto de salvado de arroz morado y evaluación de las propiedades del producto

L.T.K. Loan[1]*, N. V. Tai[2]

[1]*Faculty of Agriculture and Food Technology, Tien Giang University, Vietnam.*

[2]*School of Food Industry, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand.*

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Abstract

The present study examined the process of foam-mat drying "Cẩm" purple rice bran extract, including optimization foaming conditions and effect of drying temperatures on the drying behaviours and powder's qualities. The egg album and xanthan gum at different levels were used as foaming agents, which further optimizied by the response surface methodology. The optmial foam was dried at four levels of temperature (50-80 ^{o}C). Moisture content was further recorded every 30 minutes. Four common emperical models were applied for predicting the pattern of moisture content. Under the effect of heat treatment, the final qualities of Cẩm purple rice bran foam-mat dried powder were determined. The results showed that when egg albumin and xanthan gum were used, 12.04% and 0.337% could maximize foam expansion and stability. These conditions could facilitate the efficiency of the drying process. Moreover, among the four models, the Page model showed the best fit for predicting the change in moisture ratio. The effective diffusivity and activation energy were from 6.73 x 10^{-10} to 1.66 x 10^{-9} m^2/s and 22.72 kJ/mol, respectively. The study also revaled that at temperature of 70^{o}C, the product could maintain high antioxidants, proper conditions for storage and high acceptance by consumers.

Keywords: foam-mat drying, modelling, antioxidant, kinetics, optimization.

Resumen

El presente estudio examinó el proceso de secado en estera de espuma del extracto de salvado de arroz morado "Cẩm", incluida la optimización de las condiciones de formación de espuma y el efecto de las temperaturas de secado sobre los comportamientos de secado y las cualidades del polvo. Como agentes espumantes se utilizó álbum de huevo y goma xantana en diferentes niveles, los cuales se optimizaron aún más mediante la metodología de superficie de respuesta. La espuma óptima se secó a cuatro niveles de temperatura (50-80^{o}C). El contenido de humedad se registró adicionalmente cada 30 minutos. Se aplicaron cuatro modelos empíricos comunes para predecir el patrón de contenido de humedad. Bajo el efecto del tratamiento térmico, se determinaron las cualidades finales del polvo seco de estera de espuma de salvado de arroz morado Cẩm. Los resultados mostraron que cuando se utilizaban albúmina de huevo y goma xantana, el 12,04 % y el 0,337 % podían maximizar la expansión y la estabilidad de la espuma. Estas condiciones podrían facilitar la eficiencia del proceso de secado. Además, entre los cuatro modelos, el modelo de Page mostró el mejor ajuste para predecir el cambio en la proporción de humedad. La difusividad efectiva y la energía de activación fueron de 6,73 x 10^{-10} a 1,66 x 10^{-9} m^2/s y 22,72 kJ/mol, respectivamente. El estudio también reveló que a una temperatura de 70^{o}C, el producto podría mantener altos niveles de antioxidantes, condiciones adecuadas para su almacenamiento y alta aceptación por parte de los consumidores.

Palabras clave: secado de estera de espuma, modelado, antioxidante, cinética, optimización.

Corresponding author. E-mail: lethikimloan@tgu.edu.vn;

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1 Introduction

Rice is well recognized as a significant staple food around the globe. In the country of Vietnam, a diverse range of rice cultivars were planted and harvested on a yearly basis. According to Van Tai *et al.* (2023), rice production in Vietnam generates a significant quantity of waste that has the potential to be transformed into value-added products. Rice bran is identified as one of the byproducts generated during the process of rice cultivation. A study conducted by Huang and Lai (2016) demonstrated that rice bran is a rich source of several nutrients and antioxidant chemicals. The quality of rice is commonly attributed to the presence of substantial quantities of bioactive compounds such as dietary fiber, tocopherols, tocotrienols, oryzanols, phytic acid, and phenolic compounds (Arab *et al.*, 2011; Loan *et al.*, 2024). According to Ngo *et al.* (2022), it is possible that these bioactive chemicals have the capacity to decrease the glycemic index and exhibit antidiabetic properties. According to Thuy *et al.* (2022a), the rice bran was shown to contain a significant amount of vitamins and minerals. The rice variety known as "Cẩm", which has its origins in Tien Giang province in Vietnam, possesses a distinctive purple outer layer. It has traditionally been utilized for culinary purposes and has also served as a primary ingredient in the production of a range of products, including instant rice, germinated rice flour, and gluten-free bread (Le Loan *et al.*, 2021; Le *et al.*, 2022; Le & Nguyen, 2019; Loan *et al.*, 2023c; Tai *et al.*, 2023). Nevertheless, subsequent to undergoing the milling and polishing procedures, the rice bran known as "Cẩm" was also discarded, and its utilization was not appropriately executed (Loan *et al.*, 2023a; Loan *et al.*, 2023b). In a recent study conducted by Loan *et al.* (2023a), it was shown that the "Cẩm" rice bran possesses significant potential for the development of value-added products. This is attributed to its high protein content and the presence of other essential elements. Additionally, a separate study conducted by Loan *et al.* (2023b) demonstrated that these particular rice cultivars exhibit a notable concentration of anthocyanins, specifically measuring at 46.3 mg/100g. The extraction was optimzed (Loan *et al.*, 2023b), however, further study need for applying in foods.

In general, various drying procedures, including freeze drying, microwave drying, vacuum drying, and infrared drying, are frequently employed (Sangamithra *et al.*, 2015). Nevertheless, the use of this technology necessitates substantial financial commitment and incurs significant energy expenses, while also occasionally demanding superior product quality (Farid *et al.*, 2022; Sangamithra *et al.*, 2015). Consequently, hot-air drying is a viable method that is typically employed, and it generally yields a reduced moisture content compared to the initial material (Farid *et al.*, 2022). Nevertheless, this approach also presents several drawbacks, such as heightened energy consumption and diminished sensory, nutritional, and functional attributes. The effective moisture diffusivity is diminished as a result of the shrinkage and texture compaction phenomena that occur during typical hot-air drying. According to previous research, the duration of heat exposure during the drying process should be minimized in order to mitigate the negative impact on the quality of the food product by reducing water loss (Kanha *et al.*, 2022; Thuy *et al.*, 2022e). The foam-mat process was recently succesfully applied for producing various dried powders from extract and juice fruits, such as butterfly pea flower (Thuy *et al.*, 2023), cornelian cherry pulp (Güldane, 2023), Gardenia extract (Thuy *et al.*, 2022c), mullberry extract (Thuy *et al.*, 2022d), magenta leaves extracts (Thuy *et al.*, 2022e). The study by Güldane (2023) used egg protein and pectin for foaming conditions. The process was aided by sonication processing. In addition, egg albumin, carboxymethyl cellulose, and digestion-resistant maltodextrin were used for foaming the extract from mullbery (Thuy *et al.*, 2022d), which also showed good foaming conditions. However, most studies used egg album and xanthan gum as foaming agents due to high foaming properties as foaming stability and foaming expansion (Thuy *et al.*, 2022c; Thuy *et al.*, 2023; Thuy *et al.*, 2022e). These products maintained a high content of antioxidants as well as high acceptability from a consumer perspective. Nevertheless, there has been a lack of research on the utilization of foam drying technology for rice bran extract. The implementation of foam-mat drying, a method that involves the formation of foam from a liquid, has the potential to mitigate these challenges. In order to achieve stability, the liquid is subjected to agitation until it forms a consistent foam. Subsequently, the drying behavior and quality of the product are influenced by the drying temperature. A good understanding of the drying behavior and quality change of rice bran foams into foam powders could contribute in this respect, as foams and foam powders are potentially suitable for use as food foam or for cream-based applications and noodles. The kinetic aspect of nutritional attributes has become crucial. This helps in understanding the degradation of valuable compounds present in food during processing (Sarpong *et al.*, 2018). So far, there are limited works on foam mat drying of rice bran extract, and data regarding the encapsulation efficiency of foam mat-dried powder have been reported, especially since this is the first study on Cẩm rice bran from Vietnam. Therefore, the aim of this study is to optimize the foaming conditions and study as well as evaluate the drying behaviors and changes in the physicochemical properties of foam power. This study could create a promising ingredient for application in local cuisine in Vietnam as well as others.

2 Materials and methods

2.1 *Materials*

"Cẩm" rice bran (CRB) was collected from the local company in Tien Giang province (Vietnam). The defatted CRB was extracted by microwave-assisted technique under optimal conditions (at an energy level of 500 W for 5 mins) and dried to get the powder form as presented in the study of Loan *et al.* (2023b).

2.2 *Foaming conditions*

The experiment involved the investigation of foam generation and stabilization, utilizing two components and three stages. The application of the central composite design (CCD) was utilized in order to determine the best circumstances that would maximize the expansion and stabilization of foam. The CRB extract was combined with an emulsifier, specifically egg albumin ranging from 9% to 15%, and stabilizers, specifically xanthan gum ranging from 0% to 0.5%, in a mixer (Philips HR 3705-300 W, USA) operating at the highest speed for a duration of 10 minutes to facilitate the development of foam (Thuy *et al.*, 2022c; Thuy *et al.*, 2022d). The foam expansion and foam stability were analyzed, which followed the described method of Thuy *et al.* (2022d). Briefly, the foaming expansion was calculated by dividing the difference in volume of foam after whipping and the initial volume by the initial volume of the mixture. The whipped foam was carefully transferred into a transparent volumetric cylinder and thereafter allowed to equilibrate at room temperature for a duration of 2 hours. The measurement of the liquid volume extracted from the foam through drainage revealed a reduction in the overall foam volume. Multiple regression analysis with response surface methodology was applied to find the optimal conditions of the foaming process where the highest foam expansion and stability could be achieved.

2.3 *Drying conditions*

After selecting optimal foaming conditions by multiple regression analysis, it was used as the constant operation for the drying process as below. The foam-mat mixture of CRB extract was made in accordance with the foaming method as above-mentioned. The mixture was subsequently transferred to stainless steel trays (2 trays) with a surface area of 1 square meter. The thickness of the foam in each tray measured 4 mm. The sample was subjected to drying in a Binder FD115 oven from Japan, with an air velocity of 1.0 m/s, at four distinct temperatures (50, 60, 70, and 85^{o}C). The drying process continued until the moisture content of the sample achieved equilibrium, which was roughly 4-6% as denoted by Me. The collected sample underwent a process of fine grinding and was afterwards collected following its passage through a 100-mesh screen. It was then stored under dark conditions at a temperature of 4^{o}C until it was ready for further examination.

The moisture content (M_o) at the beginning of the drying process of each experiment and the moisture content (M_t) at each 30-minute interval were determined by calculating from the recorded weight of the sample at every 30 mins with M_o of foam, in order to calculate the moisture ratio (MR) using Equation 1. All the moisture content for applying the emperical models was measured and calculated on a dry basis.

$$MR = \frac{M_t - M_e}{M_o - M_e} \tag{1}$$

In this study, we employed four widely recognized thin-layer models, namely Henderson and Pabis, Page, Logarithmic, and Two-term models, to forecast the variation of MR within the temperature range under investigation (as shown in Table 1). The predictive kinetic models for determining the moisture content of foam-mat dried products in an oven were frequently employed (Thuy *et al.*, 2022e). The selection of appropriate models was primarily based on the evaluation of the coefficient of determination (R^2), chi-square (χ^2), and root mean square error (RMSE).

The effective diffusivity and activation energy was follow the law of Fick and caculation as the described by Thuy *et al.* (2022e). A equation proposed by Crank (1979) can be obtained in the context of the drying process, with the assumptions of one-dimensional moisture transport, limited shrinkage, constant diffusivity, uniform initial moisture distribution, and low external hindrance. The Arrhenius equation is employed for the purpose of determining the activation energy (E_a), which quantifies the relationship between the effective diffusion coefficient and the temperature at which air drying occurs.

Table 1. Thin-layer models and their equation.

Model No.	Model name	Equation
1	Henderson and Pabis	$MR = ae^{-kt}$
2	Page	$MR = ae^{-kt^n}$
3	Logarithmic	$MR = ae^{-kt} + c$
4	Two-term	$MR = ae^{-kt} + be^{-k_0 t}$

Note: a, b, c, n, k, k_o are the model constants.

2.4 Product's quality analysis

The foam-mat powder from CRB extract under different drying temperatures was analyzed for its final qualities, including white hunterness, total phenolic content, total anthocyanin content, moisture content, water activity, and antioxidant activities by DPPH and FRAP assays. The obtained data was compared using ANOVA.

Total phenolic compound was analyzed using the Folin-Ciocalteu assay (Van Tai *et al.*, 2021). While the total anthocyanin content was followed the differential pH method as describe by Thuy *et al.* (2022e). Moisture content was used the moisture analyzer (PCE MA-50X, Japan) for recording and water activity also determined by Water Activity Meter (Aqualab, Japan). Colorimeter (Monica, Japan) was used for recording the color parameters. The antioxidant activities analysis was conducted as the method of Loan *et al.* (2023b).

The acceptance of color score was average from the score of 50 panelists, which performend as discription of Thuy *et al.* (2020a). The rating scale from 1 to 9 (to very dislike to like very much).

2.5 Thermal degradation analysis

The kinetics of degradation of anthocyanin during the foam-mat drying process at the selected temperature were analyzed following first-order kinetics. The data on total phenolic compound and total anthocyanin content at different collected times (C_t) was fitted with the equation below (Equation 2). The initial content of foam from CRB extract was also analyzed (C_o).

$$C_t = C_o e^{-kt} \tag{2}$$

The calculation of the decimal reduction time (D value, hour) involved the utilization of the reaction rate constant (k), as determined by Equation 3 (Singhal *et al.*, 2020).

$$D = \frac{2.303}{k} \tag{3}$$

3 Results and discussion

3.1 Optimization foaming conditions for foam-mat drying process

Foaming expansion and stability are two of the most important factors for the foam-mat drying process. The high expansion and good stability could maintain the quality as well as reduce the drying time (Dehghannya *et al.*, 2018; Thuy *et al.*, 2023). Egg albumin in this study contributed to the foaming production, and xanthan gum was considered to have foaming stability (Martínez-Padilla *et al.*, 2015). Using the CRB extract for the foaming process, the expansion and stability of the foam were changed and influenced by the content of egg albumin and xanthan gum. Regression models between the response (foam expansion and foam stability) and the variable (concentration of egg albumin and xanthan gum) were established with high goodness of fit ($R^2 > 90\%$ and R^2 adjusted $> 80\%$), as shown in Table 2. Evidently, the P-value of the lack of fit of both models was higher than 0.05, which indicated adequate prediction of the models. However, among linear, intercept, and square terms, the intercept term (AB) had a P value greater than 0.05. Therefore, the AB term was removed from the regression equations (Equations 3 and 4).

$$\text{Foam expansion } (\%) = -228.47 + 78.27A + 257.35B - 3.2014A^2 - 432.81B^2 \tag{4}$$

$$\text{Foam stability } (\%) = -92.63 + 24.44A + 154.63B - 0.92A^2 - 138.80B^2 \tag{5}$$

where: A is egg albumin concentration (%) and B is xanthan gum concetration (%).

The countor plots obtained by applying the response surface methodology presented the effect of variables on the responses (Figures 1 and 2). Foam expansion and stability varied by the fuction of egg albumin and xanthan gum. The expansion and stability of foam ranged from 220 to 320% and from 60 to 93%, respectively. A moderate concentration of foaming agent was recommended due to the slight decrease in foam expansion and stability at the high level of addition. High expansion and stability could promote the conductivity of the drying process, which could reduce the drying time due to more area for air-drying contact (Güldane, 2023; Sifat *et al.*, 2021). For achieving maximum expansion and stabilization of foam, it is advisable to utilize a moderate dosage of the foaming ingredient together with a proper duration of whipping. During the process of whipping, the air that is introduced becomes entrapped inside the fluid foam in the form of bubbles. This phenomenon leads to a drop in density, resulting in an increase in the porosity of the foam (Sifat *et al.*, 2021).

To maximize the foam expansion and stability, multi-optimization selection was applied to get the most optimal conditions. The results showed that the highest value of response was achieved when egg albumin and xanthan gum were used at 12.04% and 0.337%, respectively (Figure 3). The results were also in agreement with the study of Thuy *et al.* (2022d). The validation of experimental and actual conditions also showed no significant difference. Therefore, these conditions were constantly used in the next study.

Table 2. Analysis of variance for foam expansion and stability model.

Source	Foam expansion		Foam stability	
	F-Ratio	P-Value	F-Ratio	P-Value
A	202.71	0.0446	163.96	0.0496
B	485.87	0.0289	334.16	0.0348
A^2	843.33	0.0219	433.12	0.0306
AB	16.06	0.1557	26.65	0.1218
B^2	304.48	0.0364	195.02	0.0455
Lack-of-fit	36.59	0.1192	26.32	0.1402
R^2 (%)	93.44		92.53	
R^2 adjusted (%)	85.25		83.17	

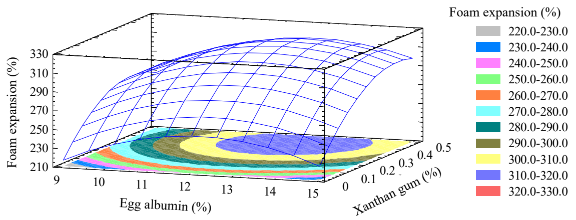

Figure 1. Countor plot effect of concentration of egg albumin and xanthan gum on foam expansion.

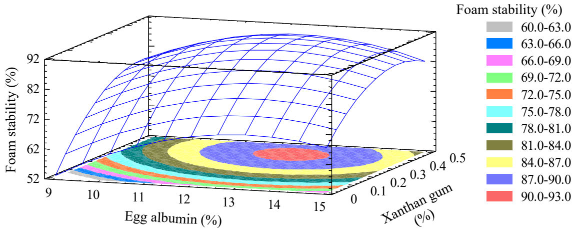

Figure 2. Countor plot effect of concentration of egg albumin and xanthan gum on foam stability

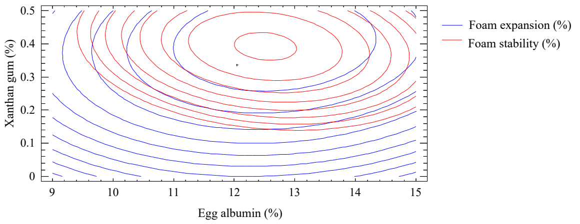

Figure 3. Overlay plot effect of concentration of egg albumin and xanthan gum on foam expansion and stability.

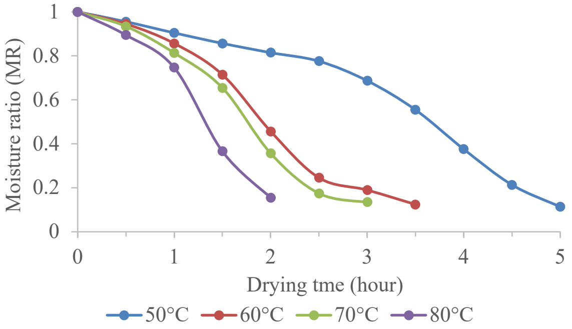

Figure 4. MR versus drying time under different drying temperatures.

3.2 *Mathematical modelling and drying behaviours*

During the drying process, the moisture content of the material changed, which could affect the moisture ratio. As shown in Figure 4, the moisture ratio of the foam-mat of CRB extract was varied under different temperatures. The long time required when the lower temperature was conducted It is due to the energy supply that the movement of moisture out of the foam mat was less, therefore the time was prolonged (Tai *et al*., 2021; Thuy *et al*., 2022b; Thuy *et al*., 2021). Besides, foam-mat drying is regarded as a cheap and straightforward technique within the realm of drying technologies. According to Hardy and Jideani (2017), the presence of a porous structure in foam is associated with an increased rate of heat transmission and a consequent reduction in drying time. According to the findings of Ratti and Kudra (2006), foam-mat drying has been identified as a viable method for the processing of biomaterials that are challenging to dry, particularly those containing heat sensitive compounds. Additionally, this technique allows for the production of materials that exhibit rapid rehydration properties, while simultaneously preserving key quality indicators such as color, scent, texture, and nutritional content. The observed characteristics can be attributed to a reduced duration of exposure to lower temperatures in the case of convective drying of non-foamed materials, leading to a decrease in thermal deterioration of the dried products. Evidently, a steady reduction of MR was observed when the process was at 50^{o}C. However, the MR dramatically changes when the temperature is above 60^{o}C. By applying the foam-mat drying process, the total time for drying could be observed at a value of 2 hours at 80^{o}C. As far as the CRB was high in antioxidant content and activities, the shorter time of drying also might maintain the higher content of these compounds.

The kinetic properties of food moisture content during the dehydration process are significant factors that influence both the overall quality of the finished product and the operational costs involved.

Table 3. Drying kinetic of CRB extract by foam-mat drying under different temperatures.

	Temp. (^oC)	Model constants						Model parameters		
		a	k	n	c	b	k_o	R^2	RMSE	χ^2
Henderson and Pabis	50	1.122	0.236					81.91	0.1367	0.023
	60	1.129	0.461					89.51	0.1247	0.021
	70	1.118	0.508					88.44	0.1338	0.025
	80	1.091	0.629					85.93	0.1556	0.04
Page	50		0.021	2.803				96.92	0.0555	0.004
	60		0.165	2.171				98.84	0.0396	0.002
	70		0.197	2.276				98.87	0.0402	0.002
	80		0.343	2.488				98.79	0.0458	0.004
Lograthimic	50	1.966	0.11		-0.853			88.01	0.118	0.019
	60	1.992	0.193		-0.888			94.94	0.0949	0.014
	70	1.985	0.217		-0.885			94.32	0.1049	0.019
	80	2	0.276		-0.909			92.07	0.143	0.051
Two-term	50	0.561	0.236			0.561	0.236	81.91	0.155	0.038
	60	0.564	0.461			0.564	0.46	89.51	0.1528	0.047
	70	0.559	0.508			0.559	0.509	88.44	0.1728	0.07
	80	0.546	0.628			0.546	0.629	85.93	0.2695	0.363

Four empirical models were also applied to predict the change of moisture ratio of foam-mat CRB extract. The evaluation of the selection models was conducted using three metrics: root mean square error (RMSE), coefficient of determination (R^2), and Chi-squared (χ^2). The results are shown in Table 3, and it can be seen that the Page model (Model 2) was the most fit to predict the change in MR. The highest average R^2 value and the lowest average RMSE and Chi-square were observed in the Page model. Recently, a page model was selected to predict the drying process of various products (Jeevarathinam *et al*., 2022; Thuy *et al*., 2020b). The effective diffusivity (D_{eff}) also changed at different temperatures. It could be seen that the increase in Deff was from 6.73 x 10^{-10} to 1.66 x 10^{-9} m^2/s when the heating temperature increased from 50 to 80^{o}C. It is comparable to the study of Tlatelpa-Becerro *et al*. (2022) on the drying process of cecina and the study of Thuy *et al*. (2022e) on the foam-mat drying of Magenta leaves. The activation energy of drying process by Pagel model was 27.22 kJ/g. The activation energy for the majority of food products typically falls within the range of 12.7 to 110 kJ/mol (Waramit *et al*., 2022).

3.3 *Quality properties of CRB foam-mat powder under different drying temperatures*

The utilization of the foam-drying technology offers numerous benefits, including a reduced drying time attributed to the unique physical composition of the foam, characterized by a honeycomb structure. This structural feature facilitates the efficient and swift elimination of moisture from liquid food products, thereby minimizing the loss of essential nutrients and moisture content in the final product (Rajkumar *et al*., 2007). The study findings indicate that an increase in drying temperature correlates with a decrease in the moisture content of the powder. The moisture content exhibited a drop from an initial value of 6.71% to a final value of 5.70% as the temperature was raised from 50 to 80^{o}C. At a drying temperature of 50^{o}C, the rate of moisture reduction in the powder was observed to be rather sluggish, necessitating an extended duration of time for the moisture content to reach 6.64% after 5 hours of drying. This particular sample exhibited a slower drying behavior compared to the other samples. The powder underwent a drying process at temperatures of 60 and 70^{o}C for a duration of 3-3.5 hours. The resulting moisture content of the powder was found to be 6.01% and 5.95% respectively. Statistical analysis revealed that there was no significant difference in moisture content between the two temperature conditions. When subjected to a drying process at a temperature of 80^{o}C for a duration of 2 hours, the foam system attains an appropriate moisture content that renders it ideal for subsequent grinding into powder. However, prolonged exposure to high temperatures during the drying process leads to undesirable alterations in the powder, such as oxidation, decomposition, and darkening, as reported in previous studies (Badmus *et al*., 2019; Sarkar *et al*., 2023).

The rise in drying temperature results in a higher rate of free water evaporation because to the enhanced heat transfer from the hot air to the foam mat. Consequently, this leads to an elevated rate of migration of free water (Franco *et al*., 2015). When the temperature rises from 50 to 80^{o}C, there is a minor drop in the water activity (a_w) from 0.324 to 0.301. The water activity of the dehydrated powder is rather low, rendering it advantageous for preservation purposes.

Table 4. Quality characteristics of powder of foam-mat dried CRB extract.

Quality characteristics	Drying temperature			
	50^{o}C	60^{o}C	70^{o}C	80^{o}C
Moisture content (%)	6.71±0.23a	6.01±0.13b	5.95±0.12bc	5.70±0.23c
Water activity	0.324±0.01a	0.313±0.02b	0.309 ± 0.01c	0.301±0.02d
Total phenolic content (mgGAE/g)	42.65±0.54a	41.85±0.54ab	38.65±0.34bc	36.65±0.23c
Total anthocyanin content (mg/ 100g)	18.35±0.44a	17.85±0.64b	16.25±0.23bc	15.25±0.24c
DPPH (%)	69.41±0.75	69.12±0.35	67.23±0.55	68.56±0.65
FRAP (μmol Trolox/g)	339.94±1.33	327.24±1.33	325.34±1.33	326.94±1.33
Hygroscopic ability (%)	18.24±0.28	19.53±0.36	21.34±0.51	23.43±0.76
Lightness value (L)	67.34±1.23	72.44±1.23	73.29±0.97	70.12±0.89
Consumer's acceptance score	6.45±0.23	7.56±0.35	8.26±0.55	8.16±0.25

Note: Value are expressed mean±standard deviation.

It has been observed that bacteria are unable to proliferate when the water activity (a_w) is below 0.85. Similarly, yeast and mold exhibit growth inhibition at even lower water activity levels, specifically below 0.70 and 0.65, respectively (Tapia *et al*., 2020). In this particular instance, the water activity and powder moisture content of foam-mat dried powder, when subjected to drying temperatures ranging from 50 to 80^{o}C, exhibit favorable characteristics suitable for storing purposes. The results obtained in this study exhibit similarities to the findings reported by Thuy *et al*. (2022e). Specifically, it was shown that the presence of powder with water activity (a_w) ranging from 0.2 to 0.3 leads to a reduction in microbial growth, as well as in oxidative and enzymatic activities. In previous research conducted on soluble powder products, it was observed that fruit powder exhibited a water activity (a_w) range of 0.2 to 0.3 (Tapia *et al*., 2020).

The intital content of TPC and TAC were 60.22 mgGAE/g and 25.34 mg/100g, respectively. Drying process led to reduction in the phenolic content due to the heat and oxidation process (Snoussi *et al*., 2021). Moreover, the observed trend suggests that an increase in drying temperature leads to a reduction in the overall phenolic content present in the dried powder product. In particular, as the drying temperature was raised to 50, 60, 70, and 80^{o}C, the foam-mat powder derived from CRB extract exhibited total phenolic content values of 42.65±0.54, 41.85±0.5, 38.65±0.34, and 36.65±0.23 mgGAE/g, respectively. The acquired total phenolic content exhibited a statistically significant disparity among the various drying temperatures. However, there was no significant difference seen between the temperatures of 50^{o}C and 60^{o}C. The crocin content in the product reached its highest level when drying temperatures were set at 50 and 60^{o}C. However, it should be noted that while drying at 50^{o}C to achieve the desired moisture content, the process required a longer duration compared to the other samples. The activation of the degradation process may be facilitated by the extended duration of drying (Thuy *et al*., 2022e; Tlatelpa-Becerro *et al*., 2022). In contrast, when subjected to temperatures of 70^{o}C and 80^{o}C, the duration of the drying process is expedited, resulting in a notable decrease in the overall phenolic content. The potential reason for this phenomenon could be attributed to the inherent susceptibility of the bioactive chemical to undergo alterations, oxidation, and decomposition when exposed to prolonged high temperatures (Thuy *et al*., 2022b; Thuy *et al*., 2023). The findings obtained exhibit a notable resemblance to the research conducted by Thuy *et al*. (2023), wherein the optimal drying temperature for the foam-drying process of butterfly pea flower extract was investigated. The same trend with the change in total phenolic compound was observed in the effect of drying temperature on anthocyanin content and antioxidant activities. Anthocyanin is heat-sensitive compounds, which could be degraded when the high heating temperature supply (Diaconeasa *et al*., 2023). Besides, the antioxidant activies postively correlated with content of antioxidant compounds (Zhang *et al*., 2023). However, during the high drying temperature, the Maildard reaction could be occured, the product from Maildard reaction could provide the high antioxidant properties (Sun *et al*., 2006). Therefore, the slightly increasing of antioxdiant activity of sample at drying temperature of 80^{o}C, was sligh increased.

The powdered leaves have a hygroscopic capacity ranging from 18.24% to 23.43%, with the most pronounced hygroscopicity observed when the powder is generated after drying at a temperature of 80^{o}C. This outcome can be attributed to the inverse relationship between the hygroscopicity value and the moisture content of the powder. The powder with lower moisture content exhibits a higher capacity to absorb moisture from the surrounding air, likely due to the moisture disparity between the product and its environment. According to Thuy *et al*. (2022c), it was shown that particles with smaller sizes had greater contact surfaces, resulting in an increased number of active sites.

The alteration in lightness was also noted in Table

4, which demonstrated an increase in the L value when higher temperatures were employed. Nevertheless, a decrease in this parameter was also observed when the temperature exceeded 70^{o}C. The accelerated browning response at higher temperatures may have contributed to the observed decrease in L value. Furthermore, it had an impact on consumer behavior regarding the ultimate product. The consumer's acceptance is observed to be influenced by the perceived value of lightness. Consumers exhibit a greater inclination towards brighter colors. Therefore, the drying temperature of 70^{o}C was selected for drying the foam of CRB extract. The degradation constant in this temperature also was calcuated and acchieved at the value of 0.1377 (1/hour) and the D value was observed at 16.7 hours. These values are comprable with the study of Süfer *et al*. (2023).

Conclusions

Foaming agent, including egg albumin and xanthan gum, greatly affect on the foaming properties. The maximum foam expansion and stability could achieve when the usage concentration of egg album and xanthan gum were 12.04% and 0.337%, respectively. Besides, under the change of moisture content, Page model was sucifiecient to describe the pattern of this value with high fitness. Moreover, the temperarture were drammatically change the physicochemical properties, antioxidant properties and consumer acceptance score. For drying the foam of CRB extract, the selected temperature was 70^{o}C, which could maintain the quality and save energy consumption. Further study should more concern about the application of this power in food industry as noodles, cakes, bread.

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