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Effect of gum arabic concentrations on drying kinetics, anthocyanin degradation and product qualities of purple rice bran extract dried by foam-mat technique

Efecto de las concentraciones de goma arábiga sobre la cinética de secado, la degradación de antocianinas y las cualidades del producto del extracto de salvado de arroz morado secado mediante la técnica de estera de espuma

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Abstract

This investigation aimed to study the effect of gum arabic on the drying characteristics, degradation rate of anthocyanin, and quality of foam-mat product from purple rice bran. Four different levels of gum arabic (GA) were applied (5-20%), with the control sample (without using gum arabic) for the foaming process. Foaming properties, including foam expansion, foam stability, and foam density, were determined and showed that the fluctuation was found when different contents of gum arabic were used. In particular, the highest value of foam expansion (386.75±9.35%) and foam stability (94.44±0.09%) was found at a level of usage GA of 10%, while the lowest foam density (0.278±0.021%) was observed. Empirical models were applied to predict the change of moisture content during the drying process, showing that the Page model was the fittest and gave the best prediction ($R^2 > 0.98$) at various concentrations of gum arabic. Besides that, following first-order kinetic, the lowest rate of anthocyanin degradation occurred when the concentration of GA was used at the level of 10%. Pearson's correlation showed the negative effect between anthocyanin degradation rate and drying rate of the constant of the Page model. Moreover, dried purple rice bran extract was added 10% of GA, which presented a high level of anthocyanin (20.34±0.82 mg/100 g), moisture content of 4.26±0.12%, water activity of 0.33±0.11, hygroscopicity of 19.82±0.11 g/100 g, and high acceptance by panelists.
Keywords: rice bran, foam-mat drying, kinetics, degradation, dehydration.

Resumen

Esta investigación tuvo como objetivo estudiar el efecto de la goma arábiga sobre las características de secado, la tasa de degradación de las antocianinas y la calidad del producto de espuma a partir del salvado de arroz morado. Se aplicaron cuatro niveles diferentes de goma arábiga (GA) (5-20%), con la muestra control (sin utilizar goma arábiga) para el proceso de espumado. Se determinaron las propiedades de formación de espuma, incluida la expansión de la espuma, la estabilidad de la espuma y la densidad de la espuma, y se demostró que se encontraba la fluctuación cuando se usaban diferentes contenidos de goma arábiga. En particular, el valor más alto de expansión de la espuma (386.75±9.35%) y estabilidad de la espuma (94.44±0.09%) se encontró con un nivel de uso GA del 10%, mientras que se observó la densidad de espuma más baja (0.278±0,021%). Se aplicaron modelos empíricos para predecir el cambio del contenido de humedad durante el proceso de secado, mostrando que el modelo de Page fue el más adecuado y dio la mejor predicción ($R^2 > 0{,}98$) en varias concentraciones de goma arábiga. Además de eso, siguiendo la cinética de primer orden, la tasa más baja de degradación de antocianinas se produjo cuando la concentración de GA se usó al nivel del 10%. La correlación de Pearson mostró el efecto negativo entre la tasa de degradación de antocianinas y la tasa de secado de la constante del modelo de Page. Además, al extracto seco de salvado de arroz morado se le añadió 10% de GA, el cual presentó un alto nivel de antocianinas (20.34±0,82 mg/100 g), contenido de humedad de 4.26±0,12%, actividad de agua de 0.33±0.11, higroscopicidad de 19.82± 0,11 g/100 g, y alta aceptación por parte de los panelistas.
Palabras clave: salvado de arroz, secado en estera de espuma, cinética, degradación, deshidratación.

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1 Introduction

The rice-producing industry in Vietnam produces a substantial amount of waste, which possesses the potential to be converted into goods that offer additional value. Rice bran is recognized as a byproduct that is produced as a result of the rice-growing process (Van Tai *et al*., 2023). Rice bran contains rich nutrients and antioxidant compounds (Thuy *et al*., 2022a). Moreover, the antioxidant compounds from rice bran might provide many health benefits such as antidiabetics (Ngo *et al*., 2022), antioxidants (Ngo *et al*., 2023), and anti-cancer (Loan *et al*., 2024). The rice cultivar referred to as "Cam Cai Lay", a purple rice originating from Tien Giang province in Vietnam, exhibits a discernible purple husk. Historically, it has been conventionally employed in gastronomy and has additionally functioned as a fundamental component in the manufacturing of other commodities, such as instant rice, sprouted rice flour, and bread suitable for individuals with gluten intolerance (Le Loan *et al*., 2021; Le & Nguyen, 2019; Loan *et al*., 2023b). However, upon the completion of the milling and polishing processes, the rice bran referred to as "Cam Cai Lay" was also thrown, and its exploitation was not effectively carried out. In a recent study, the study demonstrated that the rice bran exhibited considerable promise for the creation of value-added products. The high protein content and presence of other necessary components are the factors responsible for this feature. Furthermore, a distinct investigation carried out by Loan *et al*. (2023a) revealed that these specific rice cultivars manifest a significant presence of anthocyanins, with a precise quantification of 46.3 mg/100g. The optimization of the extraction process has been addressed by Loan *et al*. (2023a). However, additional research is required to explore its potential application in the context of food ingredients or products.

The utilization of preservation technology is crucial in order to prolong the shelf life of cantaloupe fruit and ensure the production of high-quality goods that retain the inherent characteristics of the food (Güldane, 2023; Pandiselvam *et al*., 2022). The process of foam mat drying is a cost-effective and efficient method that facilitates the rapid extraction of moisture from food substances (Güldane, 2023; Sánchez-Mesa *et al*., 2020). The process entails transforming a liquid product or puree into a stable foamy liquid or puree through the addition of foaming agents and/or stabilizing agents. The resulting foamy liquid or puree is then subjected to dehydration using convective hot air dryers or freeze-drying techniques, resulting in the formation of a thin porous sheet. This sheet is subsequently ground into a free-flowing powder (Sánchez-Mesa *et al*., 2020). Foam mat drying offers several advantages, including its suitability for dehydrating heat-sensitive, high-carbohydrate, and sticky food products. It also enables rapid drying in comparison to convective drying methods. Additionally, foam mat drying facilitates high retention of nutrients and exhibits a strong reconstitution capability (Güldane, 2023; Thuy *et al*., 2022c; Thuy *et al*., 2022d; Thuy *et al*., 2022e). Moreover, this drying technique proves to be cost-effective (Tlatelpa-Becerro *et al*., 2022). Various additives, including egg albumin, whey protein concentrate, soy protein isolate, carboxymethyl cellulose, glycerol mono stearate, methylcellulose, and xanthan gum, are employed as foaming agents during the foam mat drying process. These foaming agents also showed different effects on product quality (Çalişkan Koş *et al*., 2022). For instance, the study of Shameena Beegum *et al*. (2022) used using sodium caseinate and maltodextrin for production the of coconut milk powder. The research showed that the product had excellent flowability and had potential for upscale through economic evaluation. Egg albumin is also used for the production of bitter orange (*Citrus aurantium* L.) dried and Kefir through microwave-assisted foam-mat drying (Süfer *et al*., 2023; Yüksel & Pandiselvam, 2023). However, the expansion was limited due to the effect of the material used. Moreover, recent studies showed that gum arabic combined with other foaming agents was successful to applied on producing various high-quality products such as cantaloupe foam-mat powder (Suet Li *et al*., 2021), foam-mat dried soursop powder (Çalişkan Koş *et al*., 2022) and other sources (Çalişkan Koş *et al*., 2022). The opportunity to address these difficulties exists through the utilization of foam-mat drying, a technique that entails the generation of foam from a liquid substance. To attain stability, the liquid undergoes agitation until it assumes a uniform foam structure. The drying temperature has a subsequent influence on both the drying behavior and the quality of the product. A comprehensive comprehension of the drying kinetics and quality alterations of rice bran foams during the conversion into foam powders would be advantageous in this context. This is because foams and foam powders possess the potential to be utilized in many food-related applications such as food foams, cream-based products, and noodles. The study of the kinetics of dietary characteristics has assumed significant importance. This aids in comprehending the deterioration of important components inherent in food during the processing phase (Sarpong *et al*., 2018). To the best of the author's knowledge, a considerable amount of research has been conducted on the impact of various drying methods, drying temperature, and drying duration on the foam characteristics of different extracts. However, there is limited knowledge regarding the influence of gum arabic concentration on foam properties, drying kinetics, the capacity of anthocyanin protection, and physicochemical properties. Hence, the present study aimed to investigate the impact of varying concentrations of gum arabic (0%, 5%, 10%, 15%, and 20%) on the foam properties and qualities of foam mat powder from purple rice bran extract. This research provides important information that may be utilized in the development of value-added products derived from agricultural waste.

2 Materials and methods

2.1 Materials

The purple rice bran (PRB) from "Cam Cai Lay" rice cultivar was obtained from a local enterprise located in Tien Giang province, Vietnam. The extraction of the defatted PRB was conducted under microwave-assisted extraction (500 W, 5 min) (Loan *et al*., 2023a), before using it for the foaming process.

2.2 Preparation of PRB foam

From the previous research, the foaming agents, including xanthan gum and egg albumin, were used at the ratio of 12.04% and 0.337%, respectively (Loan & Tai, 2023). Different concentrations of gum arabic (GA) were added (0-20%, 5% interval) during the foaming process. After mixing all the ingredients, the mixture was whipped by a mixer (Philips HR 3705-300 W, USA) at a high-speed level for 10 minutes (Thuy *et al*., 2022c).

The foam expansion refers to the quantity of air that is integrated into rice bran extract through the process of whipping, after the introduction of foaming agents. On the other hand, foam stability was assessed by monitoring the reduction in volume every 10 minutes until it reached a consistent height, following the methodology outlined by Susanti *et al*. (2021).

The foaming density was analyzed and calculated based on the weight and volume of the foam (Susanti *et al*., 2021).

2.3 Kinetic dehydration and anthocyanin's degradation

The foam that had been created was later put onto stainless steel trays, each with a surface area measuring 1 m^2. The foam thickness in each tray was measured to be 4 mm. The sample underwent a drying process using a Binder FD115 oven (Japan). The drying process was conducted at 70°C, for 3 hours, which was followed with the methodology employed in a prior study. The drying process was carried out with an air velocity of 1.0 m/s. During the drying process, the moisture content of the sample was measured, and the anthocyanin content was determined to study the kinetics of dehydration of moisture and degradation of anthocyanins, respectively.

In order to calculate, the moisture ratio (MR) for drying modeling, the initial moisture content (M_o), and the moisture content (M_t) at 30-minute intervals were measured and recorded. Equation 1 was then employed to compute the MR.

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

Four empirical models were used to predict the change of MR during the drying process under different concentrations of GA (Table 1). The utilization of predictive kinetic models to ascertain the moisture content of foam-mat-dried items in an oven was a commonly employed approach (Thuy *et al*., 2022e). The comparison of the accuracies of the empirical drying models utilized in this study and the mass transfer approach for forecasting the moisture ratio (MR) throughout the drying process was conducted by evaluating the deviation parameters. The deviation parameters encompassed the sum of squares of error (SSE) as defined in Equation 2, the root mean square error (RMSE) as defined in Equation 3, and the chi-square value (χ^2) as defined in Equation 4, and the coefficient of determination (R^2) (Thuy *et al*., 2022e).

$$SSE = \sum_{i=1}^{n} \left(MR_{exp,1} - MR_{pre,i}\right)^2 \tag{2}$$

$$RMSE = \sqrt{\left[\frac{1}{N}\sum_{i=1}^{n} \left(MR_{exp,1} - MR_{pre,i}\right)^2\right]} \tag{3}$$

$$\chi^2 = \frac{\sum_{i=1}^{n} \left(MR_{exp,1} - MR_{pre,i}\right)^2}{N - n} \tag{4}$$

Where: MR_{exp} is the experimental moisture ratio; MR_{pre} is the predicted moisture ratio.

The degradation kinetics of anthocyanin during the foam-mat drying process at 70ºC were examined using the first-order kinetics model. Equation 2 was used to fit the data of total phenolic compound and total anthocyanin content at various collecting times (Ct). The initial content of anthocyanin in the foam of PRB extract was denoted as C_o.

Table 1. Thin-layer models and their equation

Model name	Equation
Page	$MR = ae^{-kt^n}$
Newton	$MR = e^{-kt}$
Henderson and Pabis	$MR = ae^{-kt}$
Logarithmic	$MR = ae^{-kt} + c$

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

$$C_t = C_o e^{-gt} \quad (5)$$

Where: g is the degradation constant of anthocyanin ($hour^{-1}$).

2.4 *Product quality analysis*

The foam-mat powder from PRB extract under different concentrations of gum arabic was analyzed for the final qualities, including total anthocyanin content, moisture content, and water activity. The total anthocyanin content followed the differential pH method as described by Thuy *et al*. (2022e). Moisture content was used by the moisture analyzer (PCE MA-50X, Japan) for recording, and water activity was also determined by the Water Activity Meter (Aqualab, Japan). The hygroscopicity (g/100 g) was analyzed as the operation of Thuy *et al*. (2022b). The acceptance of color score was average from the score of 50 panelists, which performed as described by Thuy *et al*. (2020). The rating scale is from 1 to 9 (to very dislike to like very much). Carr index and Hausner ratio were measured and calculated as the equation described by Shameena Beegum *et al*. (2022)

3 Results and discussion

3.1 *Foaming properties*

The foam expansion of foamed PRB extract was observed to fall within the range of 312-386%, as presented in Table 2, which was found to be considerably influenced by the concentration of GA. The expansion of foam demonstrated a substantial rise as the concentration of GA was elevated. Nevertheless, the foam expansion experienced a notable decrease when the PRB extract infused with 15% GA was utilized. The potential reason for this phenomenon can be attributed to the introduction of a concentration of GA exceeding 15%, resulting in an elevation of the liquid's viscosity beyond the threshold at which the maximum air volume can be sustained. Consequently, this excessive viscosity leads to the rupture of the foam structure. According to the findings of Bag *et al*. (2011) and Suet Li *et al*. (2021), the entrapment of air during whipping or mechanical mixing is unlikely to occur when the viscosity of the liquid is excessively high. As a result, the expansion of the foam is diminished and the density of the foam is heightened.

The evaluation of whipping qualities often relies on foam density. According to Suet Li *et al*. (2021), an increase in the amount of air integrated during the whipping process leads to a decrease in foam density and an increase in whipping ability. The utilization of low-density foam has the potential to enhance the efficiency of water removal during the drying process (Çalişkan Koş *et al*., 2022). This is attributed to the larger surface area provided by the foam, which facilitates the extraction of water from the sample. The foam density values observed in this study for the foam mat drying process of PRB extract varied between 0.278 and 0.321 g/cm^3 (Table 2). The results in Table 2 also indicated that augmenting the concentration of GA from 0 to 10% leads to a notable decrease in foam density. However, a subsequent rise in GA concentration has a converse effect on foam density. Previous studies have documented similar findings regarding the impact of carrier agent concentration on foam density (Suet Li *et al*., 2021). According to Abbasi and Azizpour (2016), an increase in the carrier agent resulted in a decrease in the foam density of sour cherry samples.

Ensuring the foam's composition remains stable is essential for facilitating efficient drying and facilitating the smooth removal of the sample from the trays. According to Bag *et al*. (2011), when the composition of the foam is significantly disrupted, there will be a corresponding increase in the drying time of the product and a deterioration in the overall quality of the finished product. In this study, the foam stability was found from 92.34 to 94.44%. The supplementation of GA has slightly increased the stability of the foam. The research of Darniadi *et al*. (2018) also reported a similar trend. Increasing the foaming concentration could lead to prolonging the stability of foam due to the complex and rigid matrix of foam. The foam maintained its structural integrity across all combinations. The development of foam can be influenced by the amount of lipids, salts, acids, and carbohydrates within the food matrix (Shameena Beegum *et al*., 2022). Indeed, it was shown that the stability exhibited a higher magnitude when the quantities of GA were at the level of 10%.

Table 2. Foaming properties of PRB foam under different concentrations of GA.

GA concentration (%)	Foam expansion (%)	Foam density (%)	Foam stability (%)
0	312.34±12.34	0.321±0.009	92.34±0.34
5	344.22±14.11	0.288±0.019	93.12±0.12
10	386.75±9.35	0.278±0.021	94.44±0.09
15	354.34±10.44	0.285±0.017	94.04±0.04
20	334.64±11.56	0.298±0.012	93.89±0.08

Table 3. Drying kinetics of CRB extract by foam-mat drying under different concentrations of gum arabic.

Model name	GA (%)	Model constants	R^2	RMSE	χ^2
Page	0	k = 0.1894; n = 2.2299	99.32	0.030	0.001
	5	k = 0.2369; n = 2.0313	99.11	0.034	0.002
	10	k = 0.3516; n = 1.6634	97.73	0.050	0.004
	15	k = 0.3019; n = 1.8197	98.29	0.045	0.003
	20	k = 0.2849; n = 1.8436	98.66	0.040	0.002
Newton	0	k = 0.4266	86.24	0.130	0.020
	5	k = 0.4570	88.73	0.117	0.016
	10	k = 0.5195	92.83	0.091	0.010
	15	k = 0.4966	91.19	0.102	0.012
	20	k = 0.4805	90.98	0.103	0.012
Henderson and Pabis	0	a = 1.1140; k = 0.4872	88.98	0.127	0.023
	5	a = 1.1002; k = 0.5120	90.83	0.115	0.019
	10	a = 1.0672; k = 0.5593	93.77	0.093	0.012
	15	a = 1.0794; k = 0.5422	92.49	0.103	0.015
	20	a = 1.0820; k = 0.5270	92.41	0.103	0.015
Logarithmic	0	a = 1.9720; k = 0.2110; c = -0.8747	94.85	0.097	0.017
	5	a = 1.9005; k = 0.2239; c = -0.8208	96.19	0.083	0.012
	10	a = 2.1071; k = 0.1947; c = -1.0751	98.06	0.058	0.006
	15	a = 2.2897; k = 0.1761; c = -1.2427	97.71	0.064	0.007
	20	a = 1.9152; k = 0.2194; c = -0.8578	97.37	0.068	0.008

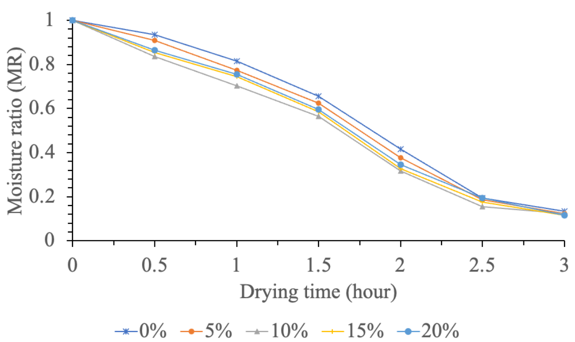

Figure 1. The change of MR during drying at 70ºC when using different concentrations of GA.

3.2 Drying kinetic and modelling

During the drying process, the moisture content of the foam was reduced and it was converted to moisture ratio (MR) as presented in Figure 1. As shown in the figure, the drying process of foam of rice bran extract was completed after 3 hours of drying at 70ºC. A faster reduction of MR was found when the GA was added at the level of 10%, and the rate was reduced when the GA level exceeded this level. It might be due to the foam properties as presented above. A high expansion could lead to the material having more chance of contact with heat and moving the water molecule out of the foam (Darniadi *et al*., 2018; Suet Li *et al*., 2021).

An additional investigation was carried out to examine the impact of GA addition on the foam-mat drying performance. This study employed empirical models for drying kinetics as a quantitative method to analyze the profile of moisture ratio (MR) during the drying process. The parameter values for each model are provided in Table 3. Almost all the drying models showed a good fit with the experimental data (R^2 > 80%). However, depending on R^2, RMSE, and χ^2, the Page model has presented the most fitness. The model incorporates a constant value (k) representing the drying rate, which falls between the range of 0.1894 and 0.3516. The k value exhibited an increase in response to the addition of GA and fell when the GA added over 10%. The role of GA in enhancing foam stability and quality to facilitate accelerated drying during the process has been observed. Following this pattern, the effective diffusivity (D_{eff}) was also the same with the trend of k value. The value of D_{eff} was from 1.264 $\times 10^{-9}$ to 1.348 $\times 10^{-9}$ m^2/s. The PRB extract foam containing 10% GA exhibited the highest D_{eff}. The observation was made that D_{eff} exhibited an increase in cases where the sample showed greater foam expansion and a decrease in cases where the foam density was lower (Azeez *et al*., 2019; Çalkşikan Koş *et al*., 2022; Suet Li *et al*., 2021).

3.3 Anthocyanin degradation

The quantification of the overall anthocyanin content in PRB foam-mat powder holds significant importance as it has the potential to influence alterations in both the visual appearance and nutritional characteristics of the product. Anthocyanin degradation of PRB extract foam was analyzed by first-order kinetics concerning drying time and concentration of GA. It could be found that the best fit of the model was found with high

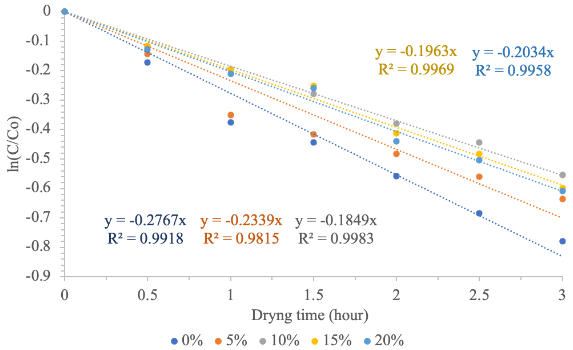

Figure 2. The degradation of anthocyanin under different concentrations of GA.

	GA	FE	FD	FS	k	g
GA	1.000					
FE	0.316	1.000				
FD	-0.463	-0.913	1.000			
FS	0.760	0.852	-0.848	1.000		
k	0.651	0.910	-0.845	0.986	1.000	
g	-0.787	-0.833	0.872	-0.994	-0.966	1.000

Figure 3. Pearson's Correlation between foaming properties and model constants.

correlation coefficients (R^2 > 0.98). From Figure 2, the degradation rate of anthocyanin was from 0.1849 to 0.2767 ($hour^{-1}$). The lowest rate was found at a level of 10%, while the control sample had the highest rate of degradation. The addition of GA could reduce the loss of anthocyanins. Anthocyanins are effectively shielded and safeguarded against the detrimental effects of oxygen and heat through a variety of functions performed by this substance (Deng *et al.*, 2023). In addition, gum arabic was commonly used as the agent for protecting the bioactive compound in many kinds of products (Jang & Koh, 2023; Mazuco *et al.*, 2018). Moreover, it is also related to the foaming properties as presented in Figure 3. Pearson's correlation showed that the degradation of anthocyanin (g) was positively related to foam density and negatively correlated to GA concentration, foam expansion, foam stability, and drying constant (k). The correlation test also confirms the previous information, the high expansion of foam could reduce the density of foam and also faster to reduce the moisture content of the material.

3.4 *Product's qualities*

The moisture level of the PRB foam-mat powder produced using various amounts of GA, as presented in Table 3, exhibited consistency with findings reported by previous researchers. The moisture range of PRB foam-mat powder was from 3.89 to 5.13%. Jaya and Das (2004) found that the moisture content of commercial instant coffee ranged from 4.18 to 5.25%, whereas the moisture level of tomato soup powders ranged from 3.4 to 4%. There was a notable reduction in the moisture content of PRB foam-mat powder as the concentration of GA rose. Nevertheless, there were no statistically significant variations seen in the concentration of GA ranging from 10% to 20%. In a study conducted by Seerangurayar *et al.* (2018), it was observed that there was a considerable drop in moisture content as the concentration of the carrier agent increased. Moreover, at this range of moisture content, it is suitable for the preservation process and could have a longer storage of the product (Rajkumar *et al.*, 2007).

Water activity is a significant quality criterion, particularly concerning food stability. The relationship between water activity and moisture content is well-established and plays a significant role in biological reactions (Tapia *et al.*, 2020). The water activity values of PRB foam-mat powder ranged from 0.33 to 0.35, as shown in Table 3. There was no observed alteration in the water activity of cantaloupe powder in response to an elevation in GA concentration. A comparable finding was identified in the analysis of barberry juice and honey powder (Seerangurayar *et al.*, 2018; Suet Li *et al.*, 2021). According to Tapia *et al.* (2020), it is widely accepted that water activity levels below 0.6 are considered to provide microbiological stability during storage. This is because microbial activities are effectively suppressed below this threshold, with most fungi exhibiting suppression below 0.7, most yeasts below 0.8, and most bacteria below 0.9. The water activity of cantaloupe powder was found to be within the range of 0.147 to 0.288, as reported by Salahi *et al.* (2017). Similarly, Kaushal *et al.* (2013) observed a water activity range of 0.40 to 0.45 for sea buckthorn leather.

Table 3. Physicochemical properties of foam mat dried PRB powder.

GA content (%)	Moisture content (%)	a_w	Hygroscopicity (g/100 g)	Anthocyanin content (mg/ 100g)
0	5.13±0.04	0.35±0.08	21.54±0.34	16.23±0.76
5	4.64±0.08	0.34±0.09	20.12±0.23	18.12±0.95
10	4.26±0.12	0.33±0.11	19.82±0.11	20.34±0.82
15	4.16±0.16	0.34±0.14	19.08±0.45	19.84±0.75
20	3.89±0.23	0.34±0.12	19.18±0.25	18.93±0.91

Hygroscopicity refers to the inherent propensity of desiccated powders to absorb moisture from the surrounding environment with high relative humidity. This characteristic is closely associated with the stability of these powders in terms of their physicochemical and microbiological properties. Understanding the hygroscopic properties of food products is crucial in determining appropriate processing methods, including drying, packaging, and storage conditions (Franco *et al*., 2016; Thuy *et al*., 2022c). According to Schuck *et al*. (2012), when the relative humidity reaches 75%, the powder's hygroscopicity classification falls within the range of 15.1-20.0 g/100g, which is deemed hygroscopic. Values exceeding this range are categorized as severely hygroscopic. The hygroscopicity of PRB foam-mat powders was shown to vary between 16.23 and 20.34%, as also indicated in Table 3 of the study. The hygroscopicity of the samples was shown to be influenced by the level of GA. This can be attributed to the high molecular weight and low hygroscopic nature of GA, which imparts a high degree of flowability to the products, preventing clumping. Seeranguraryar *et al*. (2018)conducted a study on date powders and saw a comparable pattern. The hygroscopicity of date powder ranged from 9.0 to 18.0%, with the observation that higher concentrations of carrier agents resulted in decreased hygroscopicity of the powders.

Anthocyanin is one of the main bioactive compounds of purple rice bran, which could potentially provide many health benefits. It is affected by the concentration of GA addition on the foam and presented the highest maintenance when 10% of GA was added to the foam. It is agreed with the degradation rate of anthocyanin during drying as previously mentioned. Gum arabic could protect the anthocyanin, however, it is also affected by the drying behavior during the drying process. The evaluation of consumers also showed the highest acceptance when the level of GA was used at 10%, which presented a brighter color than other samples. The final product has bright purple-blue color as seen in Figure 4.

The primary characteristics of dried powders are flowability and cohesiveness, which may be quantitatively assessed using the Carr index and Hausner ratio. The Carr index values of the cantaloupe powders varied between 7.27% and 24.18% as shown in Table 4. A higher Carr index is indicative of decreased flowability. A Carr index exceeding 20% is seen to be acceptable. Nevertheless, the utilization of a sample with a GA concentration ranging from 10% to 20% resulted in the production of powders that exhibited desirable characteristics of smooth flow. The Hausner ratio exhibited a range of values between 1.08 and 1.32. The cantaloupe powder made without the use of GA demonstrated the highest level of cohesion. According to the classification proposed by Santhalakshmy *et al*. (2015), materials with a Hausner ratio below 1.25 were categorized as having intermediate levels of cohesion. The cohesiveness of the powder was assessed based on its consistency and flowing qualities, with a lower Hausner ratio indicating improved powder flowability. In their study, Asokapandian *et al*. (2016) presented findings on the Hausner ratio and Carr index of foam mat-dried muskmelon. The results indicated that the Hausner ratio ranged from 1.12 to 1.16, while the Carr index ranged from 11.12% to 14.21%, which suggested that the muskmelon samples exhibited favorable flowability and low cohesion. Coconut milk powder had a Hausner ratio of 1.16, indicating a good flowable powder (Shameena Beegum *et al*., 2022).

Table 4. Cohesiveness and flowability of foam mat dried PRB extract powder.

GA content (%)	Carr index	Hausner ratio
0	24.18±1.15	1.32±0.02
5	22.03±1.07	1.28±0.02
10	11.52±0.37	1.13±0.01
15	8.69±0.24	1.10±0.01
20	7.27±0.80	1.08±0.01

Figure 4. The visual appearance of purple rice bran dried powder at different levels of GA.

Conclusions

The exploration of novel characteristics and/or applications derived from waste resources holds significant importance due to its profound influence on the economy, society, and environment. Indeed, the optimal utilization of natural resources has the potential to contribute significantly to the alleviation of global hunger, particularly considering the widespread integration of the food market. The utilization of foam mat drying has demonstrated its efficacy as a viable alternative for the processing of purple rice bran. The study demonstrated that the foaming of purple rice bran extract was achieved through the utilization of a 10% concentration of GA, resulting in foam with reduced density, increased expansion, and enhanced stability. Four distinct single-layer drying models were employed to forecast the foam mat drying process of purple rice bran extract foam. Among these models, the Page model demonstrated the highest suitability in predicting the drying process, with an $R^2 > 0.98$. The foam mat dried purple rice bran extract powder, made with 10% and 15% GA, demonstrated reduced moisture content, water activity, and hygroscopicity and the highest maintaining anthocyanin content. This method has facilitated the production of a product that possesses desirable characteristics suitable for both direct consumption and incorporation as a culinary ingredient. The findings presented in this study have the potential to contribute to the advancement of purple rice bran industrialization, hence facilitating the growth of small-scale producers and industries in their efforts to innovate and create novel purple rice bran-derived products. However, considering the foam mat drying technique in rice bran extract as a commercial project, the economic value should be more considered to develop the optimization conditions with the highest quality of product and profit.

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