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Effects of operating conditions on quality attributes of instant brown rice porridge prepared by microwave assisted foam-mat drying

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Abstract

Foam-mat drying combined with microwave heating was applied to produce instant brown rice porridge. Concentration of egg albumin as a foaming agent and drying parameter, air temperature and microwave power were analyzed and optimized. Results showed that concentration of egg albumin of 18% (w/w) providing lowest foam density of 0.30 g mL^{-1}, highest overrun of 223.54%, and an acceptably high value of foam stability (96.78%). Positive effects were observed with rehydration ratio and color change inversely related to drying time. Both drying parameters favorably affected textural properties including firmness, consistency, cohesiveness and viscosity index of the rehydrated samples. Response surface methodology showed good quadratic and linear correlations between input parameters for all responses, with R^2 ranging 0.81-0.99, except for the response of viscosity index (0.56). Optimal drying air temperature of 72°C and microwave power of 300 W were obtained and used for model validation. Small discrepancy errors for textural properties ranging 3.48%-24.73% showed a good basis for practical use in producing instant rice porridge.

Keywords: Foam-mat drying, Microwave heating, Response surface methodology, Foaming properties

1. Introduction

Broken brown rice obtained from the milling process is not commonly preferred by consumers but contains high nutritional components and bioactive compounds that provide health benefits [1]. Therefore, it is processed and used in numerous products such as cookies, cereals, snacks and rice porridge. Among these, instant rice porridge is an attractive product for consumers as a reasonable product, and can be produced by various methods including conventional hot air drying, freeze drying [2], drum drying [3] and extrusion [4].

Foam-mat drying also has potential for small and medium enterprises due to its simplicity and suitability for hard-to-dry materials at minimal cost [5-8]. In this process, high-viscosity liquid or semi-liquid materials are foamed by incorporation with a foaming agent, and subsequently dried in a short time due to the porous nature of foam and the enlarged evaporation surface area [8], resulting in a product with favorable rehydration [5, 9, 10]. However, heat transfer of the air trapped in the foamed materials is limited [5, 8, 11-13]. To resolve this problem, microwave is introduced to generate volumetric heat. Direct penetration of microwave energy into materials enhances poor heat conduction of the entrapped air in the foam [5]. Drying time is, therefore, accelerated compared to conventional foam-mat drying [5, 8, 11]. Here, foam-mat drying combined with microwave heating was employed to prepare instant brown rice porridge.

The optimal concentration of egg albumin as a foaming agent was determined for drying parameters as air temperature and microwave power. These two parameters impacting drying time, rehydration ratio, color difference and textural properties of rehydrated samples were investigated and optimized.

2. Materials and methods

2.1 Raw materials and rice porridge preparation

Broken brown rice (KDM105 variety) purchased from the local market was soaked in warm water (~70°C) for 120 min. It was ground and then cooked in excess boiled water with a rice-to-water ratio of 1:7. The obtained rice porridge was kept in a fridge until use. Commercial instant brown rice porridge was used as a control sample.

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2.2 Preparation of foamed rice porridge

Fresh egg albumin was used as a foaming agent. The optimal proportion was determined among concentrations ranging from 10% (w/w) to 20% (w/w). The rice porridge sample was mixed with the foaming agent and xanthan gum (2% w/w) as a stabilizer. The mixture was subsequently whipped by a hand mixer (Electrolux, model EHM3407, Thailand) at the highest speed (1,350 rpm) for 10 min.

2.3 Determination of foaming properties

Foaming properties including overrun (expansion on forming), foam density, and foam stability were determined in triplicate following the method of [14]. The determination of overrun was based on the mass (m_1) of 100 mL of the mixture using a 100-mL cylinder and the mass (m_2) of 100 mL (V) of foam, calculated using the following equation [15]:

$$\text{Overrun (\%)} = \left(\frac{m_1 - m_2}{m_2}\right) \times 100 \tag{1}$$

Foam density was determined as the mass-to-volume ratio, calculated using the following equation [16]:

$$\text{Foam density } (\text{gmL}^{-1}) = \frac{m_2}{V} \tag{2}$$

Foam stability was determined as the reduced foam volume caused by drainage. The transparent glass cylinder filled with foamed rice porridge (initial volume of foam, V_1) was left to drain at ambient temperature for 120 min. Afterward, the reduced volume of the foam (V_2) was measured and used to calculate foam stability using the following equation:

$$\text{Foam stability (\%)} = \left(\frac{V_2}{V_1}\right) \times 100 \tag{3}$$

2.4 Determination of moisture content a_w and rehydration ratio

Moisture content was determined according to the standard protocol [17], and water activity was measured using a water activity meter (Aqualab, Decagon, USA).

The rehydration method of instant rice porridge was slightly modified from [18]. Half a gram (w_1) of instant rice porridge was rehydrated in 25 mL of boiled water for 10 min. The filtrate was separated after centrifuging the mixture at 4,000 rpm for 10 min, and filtrate weight was recorded as rehydrated sample weight (w_2). Rehydration ratio was expressed as the following equation.

$$\text{Rehydration ratio} = \frac{w_2}{w_1} \tag{4}$$

2.5 Color measurement

A color meter (model ColorFlex, HunterLab Reston, VA, USA) was used to measure the lightness (L), redness (a) and yellowness (b) values of dried samples [13]. The color difference (ΔE) as affected by drying conditions was calculated using equation (5).

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \tag{5}$$

where ΔL, Δa, and Δb represents ($L-L_0$), ($a-a_0$) and ($b-b_0$), respectively, with subscript 0 presenting the original values of ground brown rice.

2.6 Textural analysis

Following the method of [19], a texture analyzer (TA-XT2i, Stable Micro Systems, United Kingdom) associated with back extrusion test was used to determine textural attributes including firmness (g), consistency (g·s), cohesiveness (g) and viscosity index (g·s). Fifty grams of rehydrated brown rice porridge was placed into an extrusion rig, comprising of a compression plate with 40 mm in diameter and a container with a height of 60 mm and diameter of 50 mm, and compressed with test and return speed of 1.5 mm s^{-1} and 10 mm s^{-1}, respectively. The distance of compression was 15 mm. Textural analysis was carried out in triplicate for all measurements.

2.7 Foam-mat drying combined with microwave heating

In this study, a domestic microwave oven (MS23F300EEK, Samsung, Thailand) was modified to supply hot air into the drying system, as shown in Figure 1. The foamed rice porridge was spread on a microwavable plastic pan with diameter of 18 cm. The thickness of foamed samples was kept constant at 2 cm. Temperatures of drying air (70°C, 80°C and 90°C) and three levels (150 W, 300 W and 450 W) of microwave intensity were chosen as the key drying parameters, while drying air velocity was fixed as 0.5 m s^{-1}. Full factorial design was performed to study the effects on the parameters, and to determine their optimal levels by means of response surface methodology.

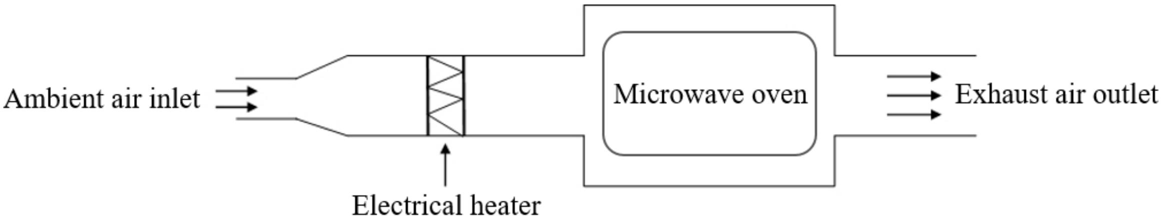

Figure 1 Schematic diagram of microwave assisted hot-air drying system

2.8 Response surface methodology and statistical analysis

In order to measure seven responses (y), including drying time (DT), rehydration ratio (RR), color difference (ΔE), firmness (Firm), consistency (Cons), cohesiveness (Cohe), and viscosity index (Vis), a full factorial design with two factors: drying air temperature (°C) and microwave power (W) with three levels was employed. All variables and their corresponding coded values are presented in Table 1. The quadratic regression, as expressed in equation (6), was employed to predict the response variables [20].

$$y = \beta_0 + \sum_{i=l}^{k} \beta_i x_i + \sum_{i=l}^{k} \beta_{ii} x_i^2 + \sum_{l \le i \le j}^{k} \beta_{ij} x_i x_j \tag{6}$$

In equation (6), β_0, β_i and β_{ii} represents the constant term of intercept, the first order, quadratic and interaction term, respectively, and β_{ij} the effect of the *ij* interaction between the factor x_i and x_j.

Desirability function was used to evaluate responses, considering the following constraints, (a) minimized drying time and color difference; (b) maximized rehydration ratio, and (c) targeted textural properties with regard to the commercial instant rice porridge's values.

Table 1 Drying variables and their corresponding coded values used for experiment

Variables	Unit	Coded values and ranges		
		-1	0	1
x_1: fluidizing air temperature	°C	70	80	90
x_2: microwave power	W	150	300	450

The results obtained were represented as the mean values of three replicates±standard deviation, and they were compared using One-way ANOVA using Tukey's test at 5% probability to determine significantly different data.

3. Results and discussion

3.1 Suitable concentration of foaming agent

Foaming characteristics play an important role in foam-mat drying [21]. Foam density, overrun and stability values as affected by concentration of egg albumin as the foaming agent are presented in Table 2. By varying egg albumin concentration, density, overrun and stability of the foamed rice porridge varied at 0.30-0.67 g mL^{-1}, 42.48-223.54%, and 96.57-98.46%, respectively.

Table 2 Foam properties for different egg albumin concentrations

No.	Egg albumin concentration (%)	Foam density (g mL^{-1})	Overrun (%)	Stability (%)
1	10	0.67±0.00^{a}	42.48±4.38^{f}	96.85±0.28^{c}
2	12	0.57±0.00^{c}	74.02±0.03^{e}	96.84±0.11^{c}
3	14	0.62±0.00^{b}	82.43±1.13^{d}	97.81±0.06^{b}
4	16	0.39±0.00^{d}	144.14±7.92^{c}	98.46±0.00^{a}
5	18	0.30±0.01^{f}	223.54±9.46^{a}	96.78±0.23^{c}
6	20	0.36±0.01^{e}	190.73±5.11^{b}	96.57±0.20^{c}

Different superscripts present significantly different data ($p<0.05$).

Foam density is one of the most important variables in foam-mat drying, as low-density foamed materials allow faster water removal [22-24]. Density of the foamed rice porridge varied from 0.30 to 0.67 g mL^{-1}. This range was consistent with [25] who obtaining foam density ranging from 0.5-0.7 g mL^{-1} with egg albumin of 40-80 g and [24] ranging 0.57-0.99 g mL^{-1}. Egg albumin concentration significantly affected foam density, which decreased with greater amounts of egg albumin, indicating more air entrapped in the foam [25]. These results were also reported by [26, 27].

Overrun is also a key parameter indicating foam formation efficiency, and was inversely related to foam density [21]. As shown in Table 2, overrun value increased when greater amounts of egg albumin were employed. At low concentration of the foaming agent, the foam was easy to drain, and thus the overrun value was low due to reduction of surface and interfacial tension [21, 28, 29]. On the other hand, increasing foaming agent concentration to 20% enhanced the viscosity of the liquid phase and prevented the trapping of air during the whipping of materials [14, 28]. Thus, this resulted in reduction of overrun at foaming agent concentration of 20%. A similar trend was reported by [28], who showed that Methocel concentration above 4% (w/w) decreased foam overrun.

Foam stability is critical when drying foamed materials. Stable foam can preserve the open-pore structure during drying, facilitating water removal under capillary diffusion mechanism [14, 25, 29]. Maximum stability of 98.46% was observed when adding egg albumin at a concentration of 16%, followed by 14%, while insignificant values were obtained from the other foaming treatment levels. Increasing trend in foam stability with greater amount of foaming agent was attributed to an increase in protein concentration which enlarged interfacial thickness film. This observation was also reported by [18].

Ideal values of foam properties for best foam quality are minimum foam density, and maximum overrun and stability. From the results in Table 2, foam treatment with albumin concentration of 18% was chosen for further investigation. This gave the lowest foam density and the highest overrun, with a high level of stability compared to the other treatments.

3.2 Effects of hot-air temperature and microwave power on drying time and rehydration ratio

The effects of air temperature and microwave power were investigated, with optimal levels determined for further experiments. All experiments were conducted until reaching the desired moisture content of approximately 5% (wb). Results in Table 3 show that final MC and a_w of dried foamed rice porridge obtained from various experimental runs were in the acceptable range of 4.41-5.34% (wb) and 0.2527-0.3892, respectively, commonly found in dried foamed materials [18, 24]. The effects of air temperature and microwave power on drying time and rehydration ratio were significant at $p<0.05$.

Table 3 Drying times and rehydration ratios as affected by hot-air temperature and microwave power

Drying conditions		MC (%wb)	a_w	Drying time (min)	RR
Air temperature (°C)	**Microwave power (W)**				
70	150	4.99±0.51	0.2667±0.0143	140^{d}	3.81±0.28^{e}
70	300	5.07±0.07	0.3479±0.0096	120^{e}	4.23±0.05^{d}
70	450	5.23±0.12	0.3173±0.0076	100^{f}	4.78±0.55^{cd}
80	150	5.46±0.24	0.2527±0.0143	140^{d}	4.28±0.03^{d}
80	300	4.99±0.17	0.2753±0.0138	120^{e}	5.29±0.04^{c}
80	450	5.34±0.09	0.2987±0.0071	100^{f}	5.39±0.10^{c}
90	150	5.12±0.41	0.3760±0.0085	120^{e}	5.33±0.11^{c}
90	300	4.41±0.26	0.3892±0.0067	100^{f}	5.69±0.01^{b}
90	450	5.25±0.13	0.3635±0.0004	80^{g}	6.65±0.03^{a}
Hot-air drying at 70°C		5.13±0.21	0.3154±0.0084	340^{a}	3.31±0.04^{f}
Hot-air drying at 80°C		5.27±0.18	0.3007±0.0113	280^{b}	3.63±0.18^{e}
Hot-air drying at 90°C		4.91±0.25	0.3509±0.0091	220^{c}	4.19±0.08^{d}
Control*		7.14±0.14	0.3033±0.0029	-	5.31±0.62^{bc}

Different superscripts present significantly different data ($p<0.05$).
*Commercial instant brown rice porridge was considered as a control sample.

In hot-air foam-mat drying with temperature ranging from 70°C to 90°C, drying time significantly decreased with increasing air temperature. Time taken to attain moisture content of approximately 5% (wb) at 70°C was 340 min, while shorter drying times of 280 min and 220 min were required at air temperatures of 80°C and 90°C, respectively with other conditions remaining the same. This is commonly observed in conventional drying processes. Higher air temperatures enhance heat and mass transfer rate, resulting in faster drying [21, 29-31]. Microwave power also affected drying time, decreasing with higher microwave intensity at all temperatures. Greater microwave energy, generating increased volumetric heat to greater depths, enhanced the mass transfer rate and resulted in faster drying [30, 31]. This result concurred with previous studies focusing on microwave drying [5, 8, 11-13].

Rehydration ratio, indicating the capability of dried matrix to absorb water, is a significant property of dehydrated materials [32]. Results in Table 3 show the rehydration ratio (RR) of foamed rice porridge dried at different temperatures and microwave powers. The RR values of the foamed rice porridge samples dried under conventional hot-air drying slightly increased with higher air temperature. This could be explained by higher moisture diffusivity inside the materials [32]. However, these results (3.31-4.19) were significantly lower than the commercial samples (5.31). To enhance the ability to absorb water during rehydration, convective hot-air drying was assisted with microwave heating at each air temperature. Results in Table 3 show that foam-mat drying combined with microwave heating resulted in higher RR values at all temperatures. At 90°C with microwave power of 450 W, maximum RR value of 6.65 was obtained. Increase in microwave intensity resulted in higher rehydration rate. Accelerated capillary diffusion facilitated water movement as well as water adsorption during rehydration before the porous structure collapsed. [2, 5, 11].

3.3 Color difference

Color difference (ΔE) is commonly used to assess qualitative change caused by process parameters [11]. Results in Table 4, show the color change with respect to ground brown rice. Samples varied between 13.97 (at 70°C plus 300 W) and 27.26 (at 90°C plus 450 W). This table shows slight increase in ΔE with more microwave intensity up to 300 W, and considerably higher at 450 W. This trend directly related to brighter samples (higher L value), where the whiter tint may be attributed to increased coagulation of egg albumin, resulting from more heat generated by microwave energy at higher intensity level [11]. A similar trend was reported by [11], while the Maillard reaction resulting in increasing browning may be a plausible explanation of significant color difference, as seen from changing redness and yellowness [13].

Table 4 Color of foam mat-dried rice porridge as affected by drying parameters

Drying conditions		L*	a*	b*	ΔE
Air temperature (°C)	Microwave power (W)				
70	150	72.15 ± 1.38^{f}	2.15 ± 0.11^{a}	20.74 ± 0.46^{a}	14.48 ± 0.33^{h}
70	300	71.36 ± 0.44^{f}	2.01 ± 0.26^{ab}	20.87 ± 0.40^{a}	13.97 ± 0.19^{i}
70	450	71.22 ± 1.87^{f}	1.71 ± 0.11^{b}	19.75 ± 0.21^{b}	14.99 ± 0.63^{g}
80	150	77.12 ± 0.17^{c}	1.76 ± 0.06^{b}	19.14 ± 0.16^{c}	18.76 ± 0.01^{e}
80	300	77.31 ± 0.12^{c}	0.61 ± 0.02^{e}	16.78 ± 0.03^{d}	20.87 ± 0.05^{d}
80	450	80.24 ± 0.01^{b}	0.10 ± 0.02^{g}	15.05 ± 0.02^{e}	24.12 ± 0.01^{b}
90	150	76.76 ± 0.11^{d}	1.01 ± 0.01^{d}	14.87 ± 0.03^{f}	21.95 ± 0.03^{c}
90	300	76.69 ± 0.36^{cde}	0.49 ± 0.05^{f}	14.99 ± 0.06^{e}	21.93 ± 0.14^{c}
90	450	83.89 ± 0.25^{a}	0.07 ± 0.02^{g}	14.14 ± 0.02^{g}	27.26 ± 0.16^{a}
Hot-air drying at 70°C		71.82 ± 0.81^{f}	2.26 ± 0.08^{a}	20.88 ± 0.17^{a}	14.14 ± 0.26^{hi}
Hot-air drying at 80°C		76.39 ± 0.14^{e}	1.77 ± 0.03^{b}	20.66 ± 0.09^{a}	17.20 ± 0.03^{f}
Hot-air drying at 90°C		77.15 ± 0.23^{c}	1.27 ± 0.07^{c}	15.08 ± 0.14^{e}	21.94 ± 0.01^{c}

Different superscripts present significantly different data ($p<0.05$).

3.4 Textural properties of rehydrated brown rice porridge

The drying mechanism directly relates to the porous structure of the instant rice porridge, which is responsible for the textural properties of the rehydrated materials. After rehydration, the rice porridge samples were subjected to the back-extrusion test, providing varied values of firmness, consistency, cohesiveness, and viscosity index as hot-air temperature and microwave power changed.

Table 5 Textural properties of rehydrated brown rice porridge as affected by drying parameters

Drying conditions		Firmness (g)	Consistency (g.s)	Cohesiveness (g)	Viscosity index (g.s)
Air temperature (°C)	Microwave power (W)				
70	150	0.47 ± 0.01^{g}	3.74 ± 0.08^{d}	0.38 ± 0.01^{b}	0.98 ± 0.07^{b}
70	300	0.69 ± 0.05^{d}	5.45 ± 0.71^{bc}	0.48 ± 0.01^{c}	1.26 ± 0.16^{cdef}
70	450	0.99 ± 0.01^{c}	6.92 ± 1.16^{ab}	0.65 ± 0.03^{e}	1.19 ± 0.04^{d}
80	150	0.61 ± 0.01^{e}	4.73 ± 0.22^{c}	0.40 ± 0.01^{b}	1.20 ± 0.03^{d}
80	300	0.74 ± 0.03^{d}	5.61 ± 0.74^{bc}	0.52 ± 0.02^{d}	1.33 ± 0.13^{def}
80	450	1.11 ± 0.03^{b}	8.09 ± 1.05^{a}	0.73 ± 0.02^{f}	1.28 ± 0.25^{bcdef}
90	150	0.70 ± 0.01^{d}	5.65 ± 0.32^{b}	0.52 ± 0.01^{d}	1.37 ± 0.03^{e}
90	300	1.16 ± 0.03^{b}	8.08 ± 1.18^{a}	0.80 ± 0.04^{g}	1.55 ± 0.27^{ef}
90	450	1.32 ± 0.05^{a}	9.39 ± 1.48^{a}	0.91 ± 0.02^{h}	1.66 ± 0.26^{f}
Hot-air drying at 70°C		0.47 ± 0.03^{g}	2.11 ± 0.24^{f}	0.29 ± 0.01^{a}	0.93 ± 0.11^{b}
Hot-air drying at 80°C		0.56 ± 0.02^{f}	2.93 ± 0.09^{e}	0.37 ± 0.02^{b}	1.12 ± 0.02^{c}
Hot-air drying at 90°C		0.72 ± 0.02^{d}	4.15 ± 0.87^{cd}	0.49 ± 0.02^{cd}	1.32 ± 0.03^{e}
Control*		0.46 ± 0.02^{g}	4.70 ± 0.18^{c}	0.29 ± 0.01^{a}	0.35 ± 0.02^{a}

Different superscripts present significantly different data ($p<0.05$).

*Commercial instant brown rice porridge was considered as a control sample.

Table 5 shows the textural properties of rehydrated brown rice porridge as affected by drying parameters. Similar trends, showing higher values with increasing drying temperature and microwave power, were observed for all attributes. The highest firmness and consistency of rehydrated rice porridge was obtained when foamed samples were dried at 90°C combined with 450 W microwave power, whereas samples dried under mildest conditions exhibited the lowest values. Similarly, the rehydrated samples prepared under extreme drying conditions showed higher cohesiveness. More water uptake during rehydration may cause a stronger structure or network inside the starch-based materials [9]. Viscosity index is a measure indicating the resistance for withdrawing the sample after specific compression. The results of this attribute showed a similar tendency to cohesiveness and consistency of the rehydrated samples. Viscosity index values increased for foamed rice porridge dried at higher air temperatures and microwave intensities. These results confirmed enhanced water uptake during rehydration, resulting in increased rice swelling at higher thermal and microwave energy [33].

3.5 Optimization of drying condition and model validation

Response surface methodology was employed to determine the correlation between input parameters and their responses. All experimental data of hot-air temperatures (T; 70-90°C) and microwave powers (MW; 150-450 W), considered as the operating factors, and their responses including drying time (DT), rehydration ratio (RR), color difference (ΔE), firmness (Firm), consistency (Cons), cohesiveness (Cohe) and viscosity index (Vis) were subjected to the quadratic equation (equation 6). However, the obtained models were reduced by means of F-test, verifying the significance of each effect or interaction ($\alpha > 0.05$). Therefore, suitable equations for each response as well as their coefficients of determination (R^2) are expressed below:

$$DT = 2445.56 - 32.39(T) - 2.99(MW) + 0.02(T)(MW) + 0.12(T)^2 + 1.41\times10^{-3}(MW)^2;\ R^2 = 0.99 \tag{7}$$

$$RR = 2.55 + 0.08(T) + 3.78\times10^{-3}(MW);\ R^2 = 0.92 \tag{8}$$

$$\Delta E = -133.73 + 3.67(T) - 0.09(MW) + 8\times10^{-4}(T)(MW) - 0.02(T)^2;\ R^2 = 0.97 \tag{9}$$

$$\text{Firm} = -1.05 + 0.02(T) + 1.8\times10^{-3}(MW);\ R^2 = 0.93 \tag{10}$$

$$\text{Cons} = -6.37 + 0.12(T) + 0.01(MW);\ R^2 = 0.81 \tag{11}$$

$$\text{Cohe} = -4.43 + 0.11(T) + 4.56\times10^{-4}(MW) - 2\times10^{-5}(T)(MW) - 7.33\times10^{-4}(T)^2 + 7.41\times10^{-8}(MW)^2;\ R^2 = 0.96 \tag{12}$$

$$\text{Vis} = 0.41 - 0.02(T) - 6.44\times10^{-4}(MW);\ R^2 = 0.56 \tag{13}$$

Finally, all estimated responses (equations 7-13) were transferred into an individual desirability function, and the overall desirability value was determined based on minimized drying time and color difference, and maximized rehydration ratio, while all textural properties were targeted to the commercial instant rice porridge's values.

According to the contour plot of desirability function in Figure 2, highest overall desirability value was 0.641, corresponding to hot-air temperature and microwave power of 72.21°C and 297.35 W, respectively. Thus, the combination of the different independent operating parameters was globally optimal. However, for practical reasons, an optimal temperature of 72°C and microwave intensity of 300 W were employed for model validation.

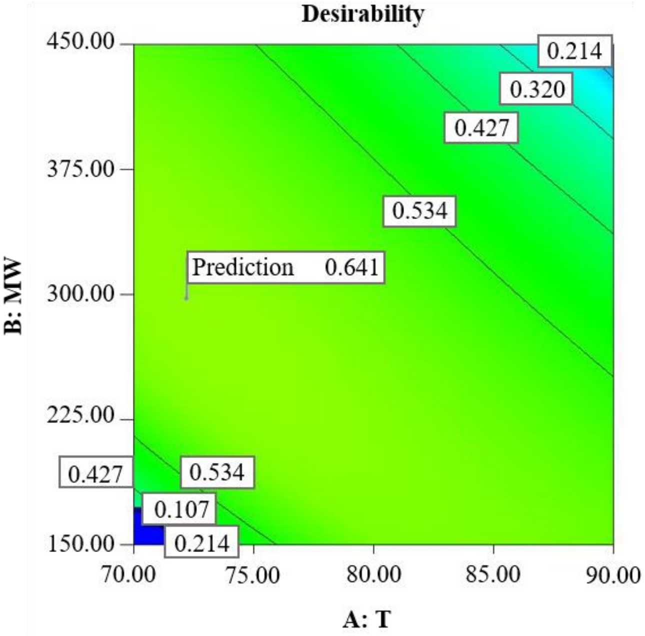

Figure 2 Contour plot of desirability function

To confirm the predicted values, a verification experiment using air temperature of 72°C and microwave power of 300 W was performed. The experimental values for drying time (DT), rehydration ratio (RR), color difference (ΔE), firmness (Firm), consistency (Cons), cohesiveness (Cohe) and viscosity index (Vis) obtained from the optimal drying conditions were 332.49 min, 4.41, 15.45, 0.73 g, 5.47 g·s, 0.50 g and 1.16 g·s, respectively (Table 6).

Table 6 Predicted and experimental values at optimal conditions

	DT (min)	RR (-)	ΔE (-)	Firm (g)	Cons (g·s)	Cohe (g)	Vis (g·s)
Predicted value	332.49	4.41	15.45	0.73	5.47	0.50	1.16
Experimental value	357±21	4.17±0.35	14.93±0.25	0.78±0.12	5.25±0.36	0.45±0.06	0.93±0.35
Percentage error	7	5.75	3.48	6.41	4.19	11.11	24.73

Small discrepancy errors lower than 10% were recorded for drying time, rehydration ratio, color difference, firmness and consistency, while higher inaccuracies were observed for cohesiveness (11.11%) and viscosity index (24.73%).

4. Conclusions

Microwave assisted foam-mat drying was applied to produce instant brown rice porridge. Foaming characteristics, as affected by concentration of egg albumin and the influences of drying air temperature and microwave power were also analyzed and optimized. Egg albumin concentration of 18% (w/w) was found to obtain favorable foaming properties. Increase in both operating parameters caused decline in drying time but increased rehydration ratio and color change. These drying inputs positively affected all textural attributes after rehydration. A good correlation and low percentage error determined optimal temperature of 72°C and microwave power of 300 W for dehydration production of instant brown rice porridge.

5. References

[1] Caceres PJ, Penas E, Martinez-Villaluenga C, Amigo L, Frias J. Enhancement of biologically active compounds in germinated brown rice and the effect of sun-drying. J Cereal Sci. 2017;73:1-9.

[2] Rhim JW, Koh S, Kim JM. Effect of freezing temperature on rehydration and water vapor adsorption characteristics of freeze-dried rice porridge. J Food Eng. 2011;104(4):484-91.

[3] Jittanit W, Lalitmassakul C, Charn-Utsar P. Quality of instant congee and energy consumption in the drying process by using drum dryer. J Syst KMUTNB. 2012;22(2):256-64.

[4] Nyombaire G, Siddig M, Dolan KD. Physico-chemical and sensory quality of extruded light red kidney bean (*Phaseolus vulgaris* L.) porridge. LWT-Food Sci Technol. 2011;44(7):1597-602.

[5] Zheng XZ, Liu CH, Zhou H. Optimization of parameters for microwave-assisted foam mat drying of blackcurrant pulp. Dry Technol. 2011;29(2):230-8.

[6] Muthukumaran A, Ratti C, Raghavan VGS. Foam-mat freeze drying of egg white-mathematical modeling part II: freeze drying and modeling. Dry Technol. 2008;26(4):513-8.

[7] Hardy Z, Jideami VA. Foam-mat drying technology: a review. Crit Rev Food Sci Nutr. 2017;57(12):2560-72.

[8] Qadri OS, Srivastava AK. Prototype continuous microwave foam-mat dryer: design and fabrication. J Food Sci Technol. 2021;58(9)3357-67.

[9] Muthukumaran A, Ratti C, Raghavan VGS. Foam-mat freeze drying of egg white-Mathematical modeling part I: optimization of egg white foam stability. Dry Technol. 2008;26(4):508-12.

[10] Kudra T, Ratti C. Foam-mat drying: energy and cost analyses. Can Biosys Eng. 2006;48:3.27-3.32.

[11] Qadri OS, Srivastava AK. Effect of microwave power on foam-mat drying of tomato pulp. Int Agric Eng J. 2014;16(3):238-44.

[12] Sun Y, Zhang Y, Xu W, Zheng X. Analysis of the anthocyanin degradation in blue honeysuckle berry under microwave assisted foam-mat drying. Foods. 2020;9(4):397.

[13] Qadri OS, Srivastava AK. Microwave-assisted foam mat drying of guava pulp: drying kinetics and effect on quality attributes. J Food Process Eng. 2017;40(1):e12295.

[14] Kanha N, Regenstein JM, Laokuldilok T. Optimization of process parameters for foam mat drying of black rice bran anthocyanin and comparison with spray-and freeze-dried powders. Dry Technol. In press 2020.

[15] Tan MC, Chin NL, Yusof YA, Taip FS, Abdullah J. Characterization of improved foam aeration and rheological properties of ultrasonically treated whey protein suspension. Int Dairy J. 2015;43(7):7-14.

[16] Rajkumar P, Kailappan R, Viswanathan R, Raghavan GSV, Ratti C. Foam mat drying of alphonso mango pulp. Dry Technol. 2007;25:357-65.

[17] AOAC. Official of analysis of AOAC International. 17th ed. Arlington, USA: AOAC International; 2000.

[18] Ng ML, Sulaiman R. Development of beetroot (*Beta vulgaris*) powder using foam mat drying. LWT-Food Sci Technol. 2018;88:80-6.

[19] Syahariza ZA, Yong HY. Evaluation of rheological and textural properties of texture-modified rice porridge using tapioca and sago starch as thickener. Food Measure. 2017;11:1586-91.

[20] Candioti LV, de Zan MM, Camara MS, Goicoechea HC. Experimental design and multiple response optimization. Using the desirability function in analytical methods development. Talanta. 2014;124:123-38.

[21] Sangamithra A, Venkatachalam S, John SG, Kuppuswamy K. Foam mat drying of food materials: a review. J Food Process Preserv. 2014;39(6):3165-74.

[22] Falade KO, Adeyanju KI, Uzo-Peters PI. Foam mat drying of cowpea (*Vigna unguiculata*) using glyceryl monostearate and egg albumen as foaming agents. Food Res Technol. 2003;217:486-91.

[23] Abbasi E, Azizpour M. Evaluation of physicochemical properties of foam mat drying dried sour cherry powder. LWT-Food Sci Technol. 2016;68:105-10.

[24] de Col CD, Tischer B, Flores SH, Rech R. Foam-mat drying of bacaba (*Oenocarpus bacaba*): process characterization, physicochemical properties, and antioxidant activity. Food Bioprod Proc. 2021;126:23-31.

[25] Benkovic M, Pizeta M, Tusek AJ, Jurina T, Kljusuric JG, Valinger D. Optimization of the foam mat drying process for production of cocoa powder enriched with peppermint extract. LWT-Food Sci Technol. 2019;115:108440.

[26] Sankat CK, Castaigne F. Foaming and drying behavior of ripe bananas. LWT-Food Sci Technol. 2004;37:517-22.

[27] Shaari NA, Sulaiman R, Rahman RA, Bakar J. Production of pineapple fruit (*Ananas comosus*) powder using foam mat drying: effect of whipping time and egg albumin concentration. J Food Process Preserv. 2018;42:e13467.

[28] Karim A, Wai C. Characteristics of foam prepared from starfruit (*Averrhoa carambola* L.) puree by using methyl cellulose. Food Hydrocoll. 1999;13:203-10.

[29] Qadri OS, Srivastava AK, Yousuf B. Trends in foam mat drying of foods: special emphasis on hybrid foam mat drying technology. Crit Rev Food Sci Nutr. 2020;60:1667-76.

[30] Dehghannya J, Pourahmad M, Ghanbarzadeh B, Ghaffari H. Heat and mass transfer modeling during foam-mat drying of lime juice as affected by different ovalbumin concentrations. J Food Eng. 2018;238:164-77.

[31] Dehghannya J, Pourahmad M, Ghanbarzadeh B, Ghaffari H. Heat and mass transfer enhancement during foam-mat drying process of lime juice: impact of convective hot air temperature. J Food Eng. 2019;135:30-43.

[32] Fu T, Niu L, Wu L, Xiao J. The improved rehydration property, flavor characteristics and nutritional quality of freeze-dried instant rice supplemented with tea powder products. LWT-Food Sci Technol. 2021;141:110932.

[33] Puspitowati S, Driscoll RH. Effect of degree of gelatinization on the rheology and rehydration kinetics of instant rice produced by freeze drying. Int J Food Prop. 2007;10:445-53.