



## Scientific Research

## Investigating the Effect of Resting Time and Foam Mixing Variables on Paprika Powder Produced by Microwave-Assisted Foam Drying

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## ABSTRACT

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In this study, the physicochemical and qualitative properties of paprika powder were investigated using microwave foam drying, influenced by two independent variables: resting time (0–20 minutes) and foam mixing time (1–10 minutes). The foam was prepared with 10% maltodextrin and 10% milk protein concentrate, and the resulting powder was evaluated in terms of porosity, expansion, and color characteristics. Process optimization was performed using response surface methodology (RSM). The results indicated that foam porosity significantly increased ( $p \leq 0.05$ ) with decreasing resting time and increasing mixing time, ranging from 0.058 to 0.090. This response exhibited a linear relationship with the independent variables, with a high coefficient of determination ( $R^2 = 0.97$ ). Conversely, foam expansion (ranging from 13.84 to 2.22) showed a significant linear decrease with increasing mixing time, with an  $R^2$  value of 0.57 ( $p \leq 0.05$ ). For the resulting powder, porosity ranged from 0.01 to 0.12, and the values of the color parameters  $L^*$ ,  $a^*$ ,  $b^*$ , browning index (BI), and chroma ranged from 16.48–27.33, 9.53–27.90, 13.31–87.13, 46.79–53.13, and 15.11–34.30, respectively. These parameters increased with decreasing resting time and increasing mixing time. The fitted models adequately represented the experimental data and can be used for predictive purposes. Significant ( $p \leq 0.05$ ) linear and interaction effects of the independent variables were observed for  $L^*$ ,  $a^*$ ,  $b^*$ , BI, and chroma. However, the effects on the Hue angle were not statistically significant ( $p \geq 0.05$ ). Among all responses, mixing time had the most pronounced effect, except for the Hue angle, which showed the highest coefficient in its respective model.

## 1- Introduction

Paprika is the dried and ground fruit of specific varieties of red pepper (\*Capsicum annuum L.\*), widely used as a natural food colorant in soups, stews, sausages, cheeses, snacks, salad dressings, sauces, pizzas, and confectionery products. It is a rich source of carotenoid pigments, primarily capsanthin and capsorubin [1–2]. Non-enzymatic browning is one of the main causes of color degradation in paprika. Moreover, due to its susceptibility to fungal spoilage and mycotoxin contamination, various drying methods have been employed for its processing [3].

There is a need to develop appropriate drying techniques for red pepper that minimize quality loss during processing. Hot air drying is the oldest method, but it has limitations such as long processing times and, in some cases, high temperatures that can degrade quality attributes like nutrients, color, and texture [4]. Compared to conventional methods, microwave drying offers several advantages. The effectiveness of microwave energy depends on the dielectric properties of the material, which help control heat distribution. It reduces processing time and enhances product quality [5]. In general, microwave-assisted drying has been reported to be a much faster alternative to freeze-drying, providing better quality properties and maintaining stability during storage [6]. Moreover, microwave drying has shown the highest drying rates and the lowest drying time and energy consumption compared to hot air drying [7].

Foam mat drying is a suitable method for drying heat-sensitive and sticky food materials with high sugar content that are difficult to dry using other techniques [8]. In this method, the food is transformed into a stable foam in the presence of foaming agents and stabilizers. The foam increases the surface area for heat and mass transfer, thereby reducing drying time and temperature [9–10].

The foam mat technique has been used to produce high-quality powders such as yacon powder [11], mixed fruit powder [12], kiwi powder [13], pineapple powder [14], potato powder [15], lemon juice powder [16,17], and quince powder [18], all of which have shown potential for application in various food formulations. The results indicated that foam and powder properties are significantly influenced by the concentration of the foaming agent. Foams with higher foaming agent concentrations exhibited more desirable properties. Foam thickness also affects drying time and powder characteristics; thinner foams shorten drying time. Dehghania and colleagues [18] demonstrated that increasing foam thickness leads to a decrease in water solubility index and an increase in water absorption index. Foam mat drying also enables the production of stable powders rich in phenolic compounds and anthocyanins [19].

In this context, the aim of the present study was to produce paprika powder using microwave-assisted foam mat drying under the influence of two independent variables: foam rest time and mixing time. To the best of our knowledge, no previous research has been conducted on the production of paprika powder using this method while simultaneously considering these two variables, making this study a novel contribution in the field.

## 2- Materials and Methods

### 2.1. Sample Preparation

The materials used in this study included milk protein concentrate powder (Pegah Co., Isfahan, Iran), maltodextrin with a dextrose equivalent of 20% (Golshahd Co., Isfahan, Iran), and red bell peppers (paprika) purchased from the local market in Jiroft, Iran. Other chemicals and reagents included Folin–Ciocalteu reagent, methanol, ethanol, toluene,

sodium carbonate, gallic acid, and 2,2-diphenyl-1-picrylhydrazyl (DPPH).

Fresh paprika fruits were obtained from the local market and transported to the laboratory. To prevent physiological changes, the fruits were pulped and stored at  $-18^{\circ}\text{C}$  until further analysis. Before processing, samples were thawed naturally at room temperature and kept for 2 hours to equilibrate.

To evaluate the effects of rest time (0–20 minutes) and foam mixing time (1–10 minutes), experiments were designed using Response Surface Methodology (RSM) with Design Expert software (version 11). The details of the experimental design are presented in Table 1 [20–22].

Table 1. Treatment test design

Run	A: Curing Time	B: Mixing Time	Porosity (%)	Extensibility (%)
1	0	10	0.0875	5.4808
2	20	1	0.0594	6.6364
3	20	5.5	0.0585	5.5358
4	10	5.5	0.0675	7.5999
5	10	10	0.0584	2.2215
6	20	10	0.0598	2.3766
7	0	5.5	0.0899	9.1781
8	10	1	0.0589	13.8439
9	10	5.5	0.0607	2.3768
10	0	1	0.0908	8.1286

## 2.2. Foam-Mat Drying of Paprika Using a Microwave

Paprika pulp was mixed with 10% milk protein concentrate and 10% maltodextrin. Rest time was set between 1 and 20 minutes, and mixing time ranged from 0 to 10 minutes using a laboratory mixer. The resulting foam was spread uniformly at a thickness of 5 mm onto plates. After evaluating the foam's quality attributes, it was dried using a microwave device at a defined power level of 400 W. Upon completion of the drying

process, the dried samples were ground and sieved to obtain paprika powder.

## 3. Evaluation of Foam and Paprika Powder Properties

**3.1. Foam Porosity Measurement (Air Volume Fraction) Foam porosity was determined using Equation 1, as described by [23]:**

$$\text{Foam prosity}(\varphi) = 1 - \frac{\rho_f}{\rho_l} \quad (1)$$

where:

$\rho_f$  is the foam density (g/cm<sup>3</sup>), and  $\rho_l$  is the density of the paprika pulp (g/cm<sup>3</sup>).

$$\text{Foam extensibility} = \frac{\left(\frac{1}{\rho_f} - \frac{1}{\rho_l}\right)}{\frac{1}{\rho_f}} \times 100 \quad (2)$$

where:

$\rho_f$  is the density of the foam (g/cm<sup>3</sup>), and  $\rho_l$  is the density of the paprika pulp (g/cm<sup>3</sup>).

### 3.3. Color Measurement of Powder

The color parameters of paprika powder were determined using digital imaging with a digital camera. The images were analyzed

$$\Delta E = ((L^*_0 - L^*_t)^2 + (a^*_0 - a^*_t)^2 + (b^*_0 - b^*_t)^2)^{0.5} \quad (3)$$

$$\text{Chroma} = (a^{*2}_t + b^{*2}_t) \quad (4)$$

$$\text{Hue Angle} = \tan^{-1}\left(\frac{b^*_t}{a^*_t}\right) \quad (5)$$

$$\text{BI} = \frac{x - 0.31}{0.17} \times 100 \quad (6)$$

An angle of 0° and 360° corresponds to the color red, while angles of 90°, 180°, and 270° represent yellow, green, and blue, respectively.

$$\varepsilon = 1 - \frac{\rho_b}{\rho_p} \quad (7)$$

Densities were determined by measuring the mass of the sample contained in a 100 mL graduated cylinder.

### 3.2. Foam Expansion

Foam expansion was calculated using Equation 2, as described by [23]:

using Adobe Photoshop software. The measured color parameters included:

L\* (lightness), ranging from black (0) to white (100), a\* (red/green axis), where negative values indicate green and positive values indicate red, b\* (yellow/blue axis), where negative values indicate blue and positive values indicate yellow. Additionally, the Browning Index (BI), Total Color Difference ( $\Delta E$ ), Chroma (color saturation), and Hue angle were calculated using Equations 3, 4, 5, and 6, respectively [23–24].

### 3.4. Bulk Porosity (Intra-Granular) of Powder

Bulk porosity was calculated based on the ratio of bulk density to particle density, according to Equation (7) [23]:

where:

$\rho_b$  is the bulk density ( $\text{g}/\text{cm}^3$ ), and  $\rho_p$  is the particle density ( $\text{g}/\text{cm}^3$ ).

#### 4- Statistical Analysis

In this study, statistical analysis of the treatments was conducted using Response Surface Methodology (RSM) based on a Central Composite Design (CCD), utilizing Design-Expert software (version 11) [22–25].

#### 5-Results and Discussion

##### 5.1. Evaluation of the Effect of Rest Time and Mixing Time of Foaming Agents with Paprika

A total of 10 foam treatments were prepared at the central point to determine the pure error and reproducibility of all data, based on the Central Composite Design (CCD). The levels

of independent and dependent variables, as well as the experimental data obtained from the response variables, are presented in (Table 2).

Models for all responses were developed using Analysis of Variance (ANOVA), and the corresponding results are shown in (Table 3). Several statistical parameters, including the F-value, coefficient of determination ( $R^2$ ), lack of fit, and P-value, were used to evaluate the adequacy of the models.

The model type and lack of fit were assessed at a significance level of ( $p \leq 0.05$ ), and then the final regression equations for the fitted models were proposed. All non-significant terms ( $p > 0.05$ ) were excluded, and the final regression models were developed (Equations 1–9).

Table 2. The presented models are obtained through the response surface for the responses of porosity, extensibility, foam, powder color, and porosity.

Run	A:Curing Time	B:Mixing Time	Porosity (%)	Extensibility (%)
1	0	10	0.0875	5.4808
2	20	1	0.0594	6.6364
3	20	5.5	0.0585	5.5358
4	10	5.5	0.0675	7.5999
5	10	10	0.0584	2.2215
6	20	10	0.0598	2.3766
7	0	5.5	0.0899	9.1781
8	10	1	0.0589	13.8439
9	10	5.5	0.0607	2.3768
10	0	1	0.0908	8.1286

Table 3. values of independent and dependent variables of powder

Run	A:Curing Time	B:Mixing Time	L*	a*	b*	BI	Hue angle	Chroma	Porosity
1	0	10	27.33	25.91	13.872	131.041	49.1559	29.3898	0.1161
2	20	1	17.66	11.86	6.622	92.2609	50.9229	13.5834	0.0138
3	20	5.5	21.12	16.24	8.92	105.819	50.2276	18.5284	0.1213
4	10	5.5	23.83	18.295	9.94	104.869	49.7698	20.8209	0.1221
5	10	10	26.67	27.19	13.48	134.465	46.0258	30.348	0.1123
6	20	10	26.71	25.37	12.442	123.541	45.5956	28.2566	0.1213
7	0	5.5	22.54	17.44	9.258	104.151	48.8021	19.7449	0.1165
8	10	1	16.48	9.535	5.782	82.7526	54.511	11.1511	0.0232
9	10	5.5	24.74	18.987	9.37	98.5545	49.3496	21.1731	0.1197
10	0	1	16.81	10.29	5.31	79.5339	47.6393	11.5793	0.0946

### 5.1.1. Foam Porosity

Foam porosity increased with decreasing rest time and increasing mixing time. The overall porosity values ranged from (0.058 to 0.090) (Table 3).

The results of ANOVA (Table 4) indicated that the coefficient of determination ( $R^2$ ) for

$$\text{Foam porosity: } y = +0.0734 - 0.0143x_1 - 0.0006x_2 + 0.0005x_1x_2 + 0.00033x_1^2 - 0.0028x_2^2 \text{ Eq. 1}$$

the model was (0.97), suggesting that the experimental data could be reliably fitted and

predicted by the model for foam porosity. This response was significantly affected by the (linear), (interaction), and (quadratic) effects of the independent variables ( $p < 0.05$ ).

Moreover, based on the proposed model (Equation 1), the positive coefficient of the quadratic term  $X_1^2$  confirmed the strong influence of rest time on this response. In contrast, the linear effect of mixing time showed a negative impact on porosity.

Table 4. Analysis of Variance (ANOVA) to determine model fit, regression coefficient ( $\beta$ ), coefficient of determination (adj.  $R^2$ ), and F value of predicted second-order polynomial models for foam porosity responses

Factor	Coefficient ( $\beta$ )
	<b>Porosity</b>
Intercept	0.0734
Linear	
$X_1$ : Curing time (min)	-0.0143*

<b>X<sub>2</sub>: Mixing time (min)</b>	-0.0006
<b>Interaction</b>	
<b>X<sub>1</sub>X<sub>2</sub></b>	0.0005
<b>Quadratic</b>	
<b>X<sub>1</sub><sup>2</sup></b>	0.00033*
<b>X<sub>2</sub><sup>2</sup></b>	-0.0028
<b>R<sup>2</sup></b>	0.9767
<b>Adj. R<sup>2</sup></b>	0.9475
<b>F-value (model)</b>	33.47
<b>F-value (lack of fit)</b>	0.8441
<b>P-value (model)</b>	0.0023*

Significance at the 95% level ( $p < 0.05$ )

### 5.1.2. Foam Expansion

The independent variables resulted in a decrease in foam expansion. The overall foam expansion values ranged from 2.22% to 13.84%. The highest expansion was observed at 10 minutes of rest and 1 minute of mixing (Run 8, Table 2).

As shown in Table 5, the coefficient of determination ( $R^2$ ) for the model was 0.57, indicating that the experimental data could not be reliably predicted by the model for foam

expansion. This response was significantly affected by the linear terms of the independent variables ( $p < 0.05$ )

The proposed model for this response is presented in Equation (2). The coefficients of the regression equation indicate that both independent variables had a negative effect on foam expansion.

$$\begin{aligned} \text{Extensibility: } y & \\ &= +7.37 - 0.6866x_1 \\ &\quad - 3.43x_2 \end{aligned} \quad \text{Eq. 2}$$

Table 5. Analysis of Variance (ANOVA) to determine model fit, regression coefficient ( $\beta$ ), coefficient of determination (adj. R<sup>2</sup>) and F value of predicted second-order polynomial models for foam expansion responses

Factor	Coefficient ( $\beta$ )
	Extensibility
<b>Intercept</b>	7.37
<b>Linear</b>	
<b>X<sub>1</sub>: Curing time (min)</b>	-0.6866
<b>X<sub>2</sub>: Mixing time (min)</b>	-3.43*
<b>Interaction</b>	
<b>X<sub>1</sub>X<sub>2</sub></b>	-
<b>Quadratic</b>	

$X_1^2$	-
$X_2^2$	-
$R^2$	0.5760
Adj. $R^2$	0.4548
F-value (model)	4.75
F-value (lack of fit)	0.8134
P-value (model)	0.0496*

Significance at the 95% level ( $p < 0.05$ )

### 5.1.3. Apparent Powder Porosity

The apparent porosity of the powders exhibited an increasing trend as the resting time decreased and the mixing time increased. Measured porosity values ranged from 0.01% to 0.12% (Table 6). The statistical analysis demonstrated that the fitted model was significant, and the lack of fit was not statistically significant ( $p < 0.05$ ), indicating a good fit between the model and the experimental data. This suggests that the model is suitable for predictive applications, consistent with previous findings (Franco et al., 2016).

Moreover, the high coefficient of determination ( $R^2 = 0.93$ ) reflects a strong correlation between the observed and predicted values, further supporting the robustness of the model. The porosity was influenced by linear, interaction, and quadratic effects of the independent variables. Notably, the positive coefficient of the squared term for resting time ( $X_1^2$ ) in Equation (3) highlights its significant and direct influence on the porosity response.

$$\begin{aligned} \text{Porosity: } y = & +0.1200 - 0.0120x_1 \\ & + 0.0386x_2 + 0.0119x_1x_2 \\ & + 0.0025x_1^2 \\ & - 0.0510x_2^2 \quad \text{Eq. 3} \end{aligned}$$

Table 6. Analysis of Variance (ANOVA) to determine model fit, regression coefficient (b), coefficient determination (adj.  $R^2$ ) and F value of predicted second-order polynomial models for powder responses

Factor	Coefficient ( $\beta$ )						
	L*	a*	b*	BI	Hue angle	Chroma	Porosity
Intercept	+21.94	+17.26	9.09	+102.63	+49.24	+19.53	0.1200
<b>Linear</b>							
$X_1$ : Curing time (min)	-0.0992	-0.0142	0.0001	0.5745	0.1908	-0.0288	-0.0120
$X_2$ : Mixing time (min)	5.51*	8.66*	4.47*	24.91*	-1.33	9.57*	0.0386*
<b>Interaction</b>							
$X_1X_2$	-	-	-0.3807	-	-0.9505	-	0.0119
<b>Quadratic</b>							
$X_1^2$	-	-	-	-	-	-	0.0025

$X_2^2$	-	-	-	-	-	-	-0.0510
$R^2$	0.9295	0.9742	0.9915	0.9348	0.6375	0.9763	0.9327
Adj. $R^2$	0.9094	0.9668	0.9873	0.9161	0.4562	0.9695	0.8486
F-value (model)	46.17	131.93	234.47	50.15	3.52	143.94	11.09
F-value (lack of fit)	0.3516	0.2901	0.7227	0.5411	47.61	0.1414	0.0665
P-value (model)	0.0165*	0.0001*	0.0001*	0.0001*	0.0888*	0.0001*	0.0185*

Significance at the 95% level ( $p < 0.05$ )

#### 5.1.4. Color Indices

The values of  $L^*$ ,  $a^*$ ,  $b^*$ , browning index (BI), and chroma increased as resting time decreased and mixing time increased. The observed ranges for the  $L^*$ ,  $a^*$ , and  $b^*$  values were (16.48–27.33), (9.53–27.19), and (5.31–13.87), respectively. Similarly, the BI, hue angle, and chroma values ranged from 79.53 to 134.46, 45.59 to 54.51, and 11.15 to 30.34, respectively (Table 6).

The coefficient of determination ( $R^2$ ) values indicated that, except for the BI parameter, the models provided a strong predictive fit for the color data, explaining over 90% of the variation in the responses (Table 6). Additionally, the lack-of-fit tests for all model equations (Equations 4–9).

$$L: y = +21.94 - 0.0992x_1 + 5.51x_2 \quad Eq. 4$$

$$a^*: y = +17.26 - 0.0142x_1 + 8.66x_2 \quad Eq. 5$$

$$b^*: y = +9.09 + 0.0001x_1 + 4.47x_2 - 0.3807x_1x_2 \quad Eq. 6$$

$$BI: y = +102.63 + 0.5745x_1 + 24.91x_2 \quad Eq. 7$$

$$Chroma: y = +19.53 - 0.0288x_1 + 9.57x_2 \quad Eq. 8$$

$$Hue: y = +49.24 + 0.1908x_1 - 1.33x_2 - 0.9505x_1x_2 \quad Eq. 9$$

## 6- Conclusion

This study investigated the production of paprika powder using foaming agents (maltodextrin and milk protein concentrate, MPC) and microwave drying, with a focus on

responses were statistically non-significant ( $p > 0.05$ ), confirming the adequacy of the models and their suitability for prediction purposes.

According to the ANOVA results, the linear effects of the independent variables were significant for  $L^*$ ,  $a^*$ , BI, and chroma. Both linear and interaction effects significantly influenced the  $b^*$  value ( $p < 0.05$ ). However, the hue angle was not significantly affected by either the linear or interaction terms ( $p > 0.05$ ) (Table 6).

Among all variables, mixing time had the most pronounced effect on all color parameters, except for the hue angle, which showed the highest coefficient in its respective

the effects of resting time and mixing time. The findings demonstrated that these processing parameters significantly influenced the physical and microstructural characteristics of the final powder.

Specifically, increasing both mixing and resting times had a positive impact on powder

porosity, foam expansion, and color attributes, with the most pronounced effects observed through the linear terms of both variables.

Optimization results revealed that the highest quality paprika powder was achieved at 0 minutes of resting time, 5.5 minutes of mixing time, and a microwave power of 400 W.

### Data Availability

The data used to support the finding of this study are available from the corresponding author upon request.

### Conflict Of Interest

The authors have no conflicts interest to report.

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### مقاله علمی-پژوهشی

#### بررسی تأثیر متغیرهای زمان استراحت و اختلاط فوم بر پودر پاپریکا تولید شده با روش خشک کردن فوم به کمک مایکروویو

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### چکیده

### اطلاعات مقاله

در این پژوهش، برخی ویژگی‌های فیزیکوشیمیایی و کیفی پودر پاپریکا به روش خشک کردن فوم مت با مایکروویو تحت تأثیر دو متغیر مستقل زمان استراحت در محدوده (۲۰ تا ۲۰ دقیقه) و اختلاط فوم (۱۰ تا ۱۰ دقیقه) مورد بررسی قرار گرفت. در این ارزیابی خصوصیات فوم حاصل از ۱۰ درصد مالتو دکستروز و ۱۰ درصد کنسانتره پروتئین شیر و پودر (تعیین تخلخل، انبساط و رنگ) و بهینه سازی فرآیند با استفاده از روش سطح پاسخ تعیین گردید. نتایج بررسی نشان داد که میزان تخلخل فوم با کاهش زمان استراحت و افزایش زمان اختلاط در محدوده (۰/۰۹۰-۰/۰۵۸) افزایش معناداری را نشان داد ( $p \leq 0.05$ ). این پاسخ بصورت خطی تحت تأثیر متغیرهای مستقل قرار گرفت و ضریب تبیین ( $R^2$ ) مدل برابر ۰/۹۷ شد. در حالی که میزان انبساط فوم (۲/۲۲-۱۳/۸۴) بصورت خطی تحت تأثیر زمان اختلاط قرار گرفت و کاهش یافت. مقدار ضریب تبیین ( $R^2$ ) برای این پارامتر ۰/۵۷ حاصل شد که معناداری را در سطح ۰/۰۵ درصد نشان داد ( $p \leq 0.05$ ). بر اساس نتایج حاصل برای پودر، تخلخل پودر با محدوده تغییرات (۰/۱۲-۰/۰۱) و مقادیر پارامترهای رنگی  $L^*$ ،  $a^*$ ،  $b^*$  و  $BI$  و کروما به ترتیب (۲۷/۳۳-۱۶/۴۸)، (۲۷/۱۹-۹/۵۳)، (۱۳/۸۷-۵/۳۱)، (۷۹/۵۳-۱۳/۴۶) و (۱۱/۱۵-۳۰/۳۴) شد که با کاهش زمان استراحت و افزایش زمان اختلاط افزایش یافتند. از آنجایی که مدل‌ها به طور رضایت‌بخشی به داده‌های تجربی برازش می‌کنند، می‌توان از آنها برای اهداف پیش‌بینی استفاده کرد. بررسی نتایج نشان داد که اثرات خطی و متقابل متغیرهای مستقل بر  $L^*$ ،  $a^*$ ،  $b^*$  و  $BI$  و کروما، معنی‌دار شد ( $p \leq 0.05$ ). ولی اثرات خطی و متقابل متغیرهای مستقل بر زاویه هیو غیرمعنی‌داری را نشان داد ( $p \geq 0.05$ ). بر اساس مدل‌های پیشنهادی، زمان اختلاط بیشترین تأثیر را بر تمامی پاسخ‌ها به استثناء زاویه هیو دارد که بیشترین ضریب را در مدل پیشنهادی دارد.

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### کلمات کلیدی:

پودر پاپریکا،  
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