JMBFS
Journal of Microbiology, Biotechnology and Food Sciences
International peer-reviewed scientific online journal
Published by Faculty of Biotechnology and Food Sciences

EFFECT OF FOAMING AGENTS AND DRYING TEMPERATURE ON DRYING RATE AND QUALITY OF FOAM-MAT DRIED PAPAYA POWDER

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https://doi.org/10.55251/jmbfs.10725

ARTICLE INFO

Received 10. 11. 2023
Revised 22. 3. 2024
Accepted 18. 4. 2024
Published 1. 6. 2024

Regular article

OPEN ACCESS

ABSTRACT

Recently, foam-mat drying is being considered a mild drying technique, requiring low investment costs but being particularly highly effective. This drying method is very useful for liquid or semi-liquid food products that are highly viscous and easily change qualities by heat. Liquid or finely ground foods are foamed with the assistance of surfactants (foam-creating and foam-stabilizing agents are egg albumin and carboxymethyl cellulose, respectively), followed by drying of the foam with hot air. Box-Behnken design (BBD) of response surface methodology (RSM) was designed in this study, with 3 factors and 3 levels, including egg albumin content (6-10%), carboxymethyl cellulose (CMC) (0.1-0.5%) and drying temperature (50-70ºC). The drying rate and β-carotene content of foam and product, respectively, are the indicators observed in 18 experimental runs and 6 repetitions at the central point. Use target settings for each response based on high β-carotene content and highest drying rate to produce a high-quality papaya powder product with the shortest drying time. The optimal and feasible experimental conditions for drying foam mats were achieved with albumin concentration, CMC and optimal drying temperature at 9.07%, 0.39% and 62ºC, respectively. From these optimal conditions, the optimal values of drying rate and β-carotene content were achieved as 3.41 g water/g dry matter/min and 37.95 µg/g, respectively. This study has confirmed that foam drying is a feasible method to produce good quality papaya powder, the product maintains the natural color of the original material, low moisture (8.5%) and water activity (0.35), and high rehydration ratio (4.05) when drying at 62ºC for 3 hours.

Keywords: Box-Behnken design, optimal experimental conditions, foam drying, drying speed, quality

INTRODUCTION

Papaya (*Carica papaya* L.) is a fruit tree belonging to the Caricaceae family, widely grown in tropical countries. Papaya contains many vitamins and minerals in fresh fruit (**Koul *et al.*, 2022**), especially with significant amounts of carotenoids, flavonoids and polyphenols (**Thuy *et al.*, 2018**). The β-carotene content will create good conditions for the body to metabolize vitamin A.

Papaya fruit belongs to the climacteric group, ripens quickly at room temperature and has a very short storage time, only about 2 to 3 days. Therefore, developing value-added products is the only way to prevent these losses. Papaya can be processed into a variety of products that can be preserved for a longer period of time such as jams, jellies, drinks, dried or canned products (**Devaki *et al.*, 2015**; **Thuy *et al.*, 2018**). Besides, processing papaya into powder is also a good solution to minimize post-harvest losses.

Drying is one of the oldest and most widely used methods for food preservation due to its reduced moisture content and ability to inhibit microbial and enzymatic spoilage in food. Among the drying methods used today, foam mat drying is being researched and used more due to its superior characteristics compared to traditional drying **(Kudra and Ratti, 2006)**. Foam drying has been confirmed to bring high benefits and investment costs are much lower than modern drying methods such as freeze drying and spray drying. The drying process is also quite simple and easier to do. Foaming agents and stabilizers are added to liquid or semi-liquid, heat-sensitive foods **(Chandrasekar *et al.*, 2015)**. All are created into foam by mechanical action of whipping, distributed into thin layers and the water is reduced at low temperature. Foaming agents create a large surface area, helping the moisture diffusion process better, reducing surface tension between the gas and liquid phases, increasing porosity and making the drying process faster. The final product is capable of maintaining the desired high quality (**Lobo *et al.*, 2020**).

Foam drying has also been performed for papaya powder (**Kandasamy *et al.*, 2012**); sour cherry powder (**Abbasi and Azizpour, 2016**), lemon juice (**Dehghannya *et al.*, 2019**). **Franco *et al.* (2016)** also conducted research on developing yacon juice powder using the foam mat drying technique by different in the total soluble solid content, foam thickness and drying temperature. Research on foam drying process for tomatoes, guava and banana was conducted by **Sharada (2013)** using egg albumin. However, Box-Behnken design uses the response surface method to optimize each dependent variable according to the optimal value of each independent variable and finally optimize multiple response surfaces for the process simultaneously. Drying papaya foam has not been done much yet. Most recently, the foam drying method has been applied to the process of creating powder from extracts of bright red leaves, mulberries, gardenia fruits, butterfly pea flowers... with different foaming and stabilizing agents, along with subsequent drying process (**Thuy *et al.*, 2022a; Thuy *et al.*, 2022b; Thuy *et al.*, 2022c; Thuy *et al.*, 2023**).

Papaya fruit is known to contain high sugar content and viscosity, so it is difficult to dry using traditional technology. Foam-mat drying technology has good applicability in this case. In addition, the process of simultaneously optimizing multiple dependent variables (response surface) is of great interest in industrial applications because energy costs are significantly reduced. The aim of this study is to design and optimize the influencing factors (foaming and stabilizing agents and drying temperature) on the drying rate of papaya foam and quality (β-carotene) of the product, selecting the optimal process parameters to produce high quality foam-mat dried papaya powders with the shortest drying time. The quality of the finished product was also analyzed.

MATERIAL AND METHODS

Sample selection and preparation

The papaya used for this study was fully ripe, purchased from a local garden (Can Tho City, Vietnam). After collection, the fruit was washed under running water. An amount of fully ripe fruit (about 15 kg) was peeled, and the flesh was ground with a common food processor. The fresh fruit puree were sieved to remove fibers and the smooth puree were obtained.The papaya puree was packed in plastic bags and stored in the freezer at -70ºC for its later utilization.

Experimental design for foaming and drying

Box-Behnken design (BBD) of response surface methodology (RSM) with three levels was used for the study. Based on the preliminary study, the optimization process was performed with input variables including albumin concentration from 6% to 10% (w/w), CMC from 0.1% to 0.5% (w/w) and dryingtemperature from 50ºC to 70ºC (Table 1).

Table 1 Independent variables with range and factor level

Symbol	Factors	Unit	Range and levels		
			-1	0	1
X_1	Egg albumin	%	6	8	10
X_2	CMC	%	0.1	0.3	0.5
X_3	Drying temperature	ºC	50	60	70

The optimization was conducted for multiple responses (drying rate Y_1 and β-carotene Y_2). Table 2 exhibits the total of 18 runs required for three variables employed in this experiment. The experimental plan based on Box-Behnken design consisting of 6 centre points.

Table 2 Experimental design of three variables

No.	Egg albumin (%)	CMC (%)	Drying temperature (ºC)	No.	Egg albumin (%)	CMC (%)	Drying temperature (ºC)
1	10	0.5	60	10	6	0.3	50
2	10	0.3	50	11	8	0.3	60
3	8	0.3	60	12	8	0.5	50
4	6	0.5	60	13	8	0.3	60
5	10	0.1	60	14	8	0.5	70
6	8	0.1	70	15	6	0.1	60
7	6	0.3	70	16	8	0.3	60
8	8	0.3	60	17	8	0.3	60
9	10	0.3	70	18	8	0.1	50

RSM (Statgraphics Centurion XVI software) was applied to determine the optimal conditions for foaming and drying. A full second order reaction model (Equation 1) was established.

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

where: Y ispredicted responses (drying rate, β-carotene); β_o is intercept coefficient; α_1, α_2, α_3 are linear terms; α_{11}, α_{22}, α_{33} are quadratic terms; α_{12}, α_{13}, α_{23} areinteraction terms and X_1, X_2, X_3 are independent variables

Due to its high density and viscosity, papaya puree was adjusted to a lower concentration, creating conditions for rapid foam development. In all experiments, papaya puree (100 g) was supplemented with water at a material:water ratio of 1:1 (data obtained from preliminary research). Addition of foaming and foam stabilizing agents (albumin and CMC), respectively, was arranged according to the Box-Behnken model. The mixture was foamed using a mixer (Philips HR 3705-300 W, USA) on the highest speed for 5.8 min (**Thuy *et al*., 2022a**) for the foam formation. Then the sample was spread on parchment paper with a thickness of 4 mm, placed in an air convection oven (MEMMERT, UN260, Germany) with adjusted drying temperature of 50, 60 and 70ºC with a wind speed of 1 m/s. Drying time is achieved when the sample reaches equilibrium moisture (about 7-8%). Then, the powder is ground finely and the powder passes through a sieve with a hole diameter of 0.04 mm. The powder were contained in silver stand up zipper pouch, stored in dark conditions at a temperature of about 3-5ºC until analyzed for the necessary parameters. Analytical criteria include moisture (%), water activity, color (through L*, a*, b* values), β-carotene content (µg/g), drying rate (g water/g dry matter/min). The rehydration rate of foam-mat dried papaya powder was also identified.

Physical and chemical properties analysis

The moisture content of the sample was determined according to the AOAC standard method (**AOAC, 2005**). Water activity (a_w) was measured using a RotronicHygroPalm HP23-AW-A-SET-40 measuring instrument (USA). The L*, a* and b* values of papaya powder were measured using a Hunter Lab Colorimeter (Color Flex, USA). β-carotene content was analyzed according to the method of **Fikselová *et al*. (2008)**.

Particle morphology

The morphology of the product was determined using scanning electron microscopy (JEOL model J550, Japan), according to **Thuy *et al*. (2020)**. Representative digital image of papaya powder was obtained at 750× magnification.

The rehydration ratio

The rehydration ratio was performed according to the method of **Kadam and Balasubramanian (2011)**.

Drying rate (DR) calculation

Overall drying rate is calculated according to the formula presented in the publication of **Thuy *et al*. (2021)**.

Statistical analysis

Each experiment was conducted three times, results are presented as mean±standard deviation (STD). At the same time, analysis of variance was performed using Statgraphic Centurion software (version XVI, USA) with 95% confidence.

RESULTS AND DISCUSSION

Quality of papaya used for research

The mashed papaya used for the study had water content, total soluble solids (TSS) and β-carotene of 87.15±0.03%, 10ºBrix and 17.68±0.38 µg/g, respectively. **Chukwuka *et al*. (2013)** and **Sana *et al*. (2009)** also announced similar results about the water content in papaya, 86.68% and 87.30%, respectively. The flesh of papaya is red-orange because the fruit contains high levels of β-carotene. The β-carotene value in papaya puree in this study was lower than the result of **Kandasamy *et al*. (2019)** with published data of 51.3 µg/g, while **Vega Gálvez *et al*. (2019)** announced that the β-carotene content in Chilean papaya was only about 1.629 µg/g, lower than the analysis results of this study. Total soluble solid content in papaya is in the range of 8 to 13ºBrix (**Suwanti *et al*., 2018; Kandasamy *et al*., 2019**). The differences in water content, β-carotene and TSS from the research results are mainly due to differences in plant varieties, ripeness of fruit at harvest, genotype, season, geographical location, maturity stage and growing conditions.

Effects of egg albumin, CMC concentration and drying temperature on drying rate (DR) and β-carotene content in foam-mat papaya powder

Foam was formed with the addition of albumin and CMC as foaming agent and foam stabilizer, respectively, at different concentrations. The foam is then dried at predetermined temperatures. The analysis results presented in Table 3 showed that egg albumin, CMC concentration and drying temperature affected DR and β-carotene content.

The highest DR (3.6 g water/g dry matter/min) was achieved with an albumin content (10%) used for foaming and a drying temperature of 70ºC, meanwhile, the lowest DR values (1.32 g water/g dry matter/min) was found when drying the foam system at lower temperatures (50ºC) and low albumin content used (6%), although the CMC content used is still quite high (0.3%). Thus, the research results showed that drying temperature and foaming agent contribute more to drying rate, followed by foam stabilizer. With the highest content of CMC foam stabilizer used (0.5%), supporting of appropriate drying temperature (70ºC), it also gives high DR (3.54 g water/g dry matter/min). **Olaniyan *et al*. (2017)** announced that the foam DR of tomato paste is 9.31 g/hr in hot air drying. **Sangamithra *et al*. (2015)** further stated that rapid drying is due to the capillary movement of moisture in the liquid film separating from the foam.

The high content of β-carotene was remained when increasing the concentration of foaming agent, however this content decreased at higher drying temperature, not showing a clear change when increasing/decreasing the CMC concentration. From the experimental designed according to the Box-Behnken model, the results showed that the β-carotene content changed in the range from 30.15±0.32 µg/g (at a drying temperature of 70ºC for 3.5 hours) to 38.60±0.05 µg/g (at drying temperature of 60ºC for 4 hours). The β-carotene content decreases due to its heat-sensitive nature. Our findings are quite consistent with **Muratore *et al*. (2008)** and **Auisakchaiyoung and Rojanakorn (2015)**, they reported that β-carotene degradation was caused by drying temperature in dried "Gac" aril and cherry tomatoes, respectively.

Table 3 Effects of albumin, CMC concentration and drying temperature (designed according to Box-Behnken) on DR and β-carotene

No.	Albumin (%)	CMC (%)	Drying temperature (ºC)	Drying time (hours)	Drying rate (g water/g dry matter/min)	β-carotene (µg/g)
1	6	0.3	50	8	1.32±0.03	32.69±0.14
2	8	0.5	50	7.5	1.66±0.06	33.79±1.58
3	8	0.1	50	7.5	1.79±0.04	34.51±1.18
4	10	0.3	50	7	1.84±0.01	32.90±2.08
5	6	0.1	60	4	2.68±0.30	35.40±1.15
6	6	0.5	60	4	2.90±0.05	36.30±1.14
7	8	0.3	60	3.5	3.04±0.24	38.18±0.70
8	8	0.3	60	4	3.09±0.27	38.20±0.36
9	8	0.3	60	4	3.16±0.23	37.79±0.23
10	8	0.3	60	3.5	3.18±0.24	38.22±0.37
11	8	0.3	60	4	3.20±0.16	38.36±0.22
12	8	0.3	60	4	3.23±0.17	38.60±0.05
13	10	0.5	60	3.5	3.25±0.16	36.66±0.51
14	10	0.1	60	4	3.30±0.15	37.32±0.56
15	6	0.3	70	3.5	3.33±0.11	30.15±0.32
16	8	0.1	70	3	3.43±0.07	30.68±0.53
17	8	0.5	70	3	3.54±0.06	31.29±0.23
18	10	0.3	70	3	3.60±0.01	32.84±1.44

Data was experssed as Mean±STD

Optimization of the experimental conditions

Drying rate (g water/g dry matter/min)

The results of variance analysis for papaya foam drying rate (DR) are presented in Table 4. The multiple regression model is considered the appropriate statistical model in this case to predict the DR. Although the results showed that albumin, CMC and drying temperature all affect the DR of papaya foam to form powder, it can be seen that albumin concentration X_1, drying temperature X_3 and square interaction of X_3 significantly affected the DR (P-values are very small compared to 0.05). Meanwhile, there was no significant contribution of the interactions X_1X_2, X_1X_3, X_2X_3 and square interaction of X_2 to the DR (P>0.05). The P value of the Lack-of-Fit in the ANOVA table is 0.668 (>0.05), so the model can be considered a good fit to the obtained data (95.0% confidence level). The R^2 value also determined that the model explained 96.12% of the variation in DR. The R^2 statistic (adjusted for d.f.) is also quite high at 95.33%. From the above analysis, interactions that did not have a significant impact on DR were eliminated from the model. The regression equation (Equation 2) was suitable to describe the correlation between DR and the proposed independent variables, with an R^2 of 95.84% and a standard error of estimate of 0.15.

$$Y_1 = -23.88 + 0.52\,X_1 + 0.325\,X_2 + 0.72\,X_3 - 0.026X_1^2 - 0.005X_3^2 \qquad (2)$$

Where: Y_1 is drying rate (g water/g dry matter/min), X_1, X_2 and X_3 are albumin concentration (%), CMC concentration (%) and drying tempearture (ºC), respectively.

Table 4 Analysis of variance for drying rate

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
X_1: Albumin	1.170	1	1.170	48.97	0.0000
X_2: CMC	0.101	1	0.101	4.24	0.0458
X_3: Drying temperature	19.911	1	19.911	833.09	0.0000
X_1X_1	0.133	1	0.133	5.58	0.0229
X_1X_2	0.020	1	0.020	0.84	0.3656
X_1X_3	0.049	1	0.049	2.07	0.1581
X_2X_2	0.004	1	0.004	0.17	0.6819
X_2X_3	0.0002	1	0.0002	0.01	0.9261
X_3X_3	3.599	1	3.599	150.57	0.0000
Lack-of-fit	0.038	3	0.013	0.52	0.6684
Pureerror	0.980	41	0.024		
Total (corr.)	26.246	53			
R^2 = 96.12%		R^2 (adj. for d.f.) = 95.33%		SEE = 0.15	

Besides, the main goal of the Pareto chart is to highlight the most important factor in a large set of factors. In the case of this analysis, a Pareto chart is drawn for the drying rate (Figure 1), illustrating the statistical impact (p<0.05) of the independent variables on the Y_1 response.

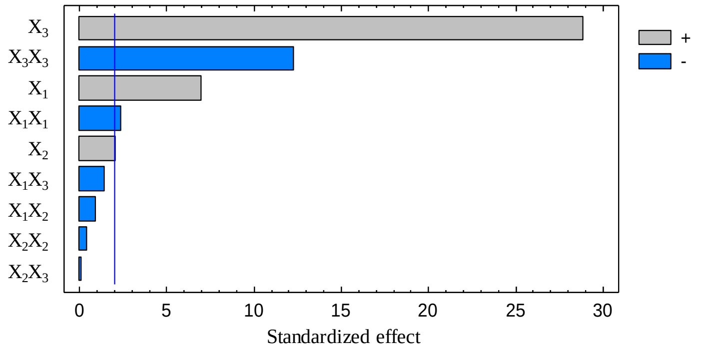
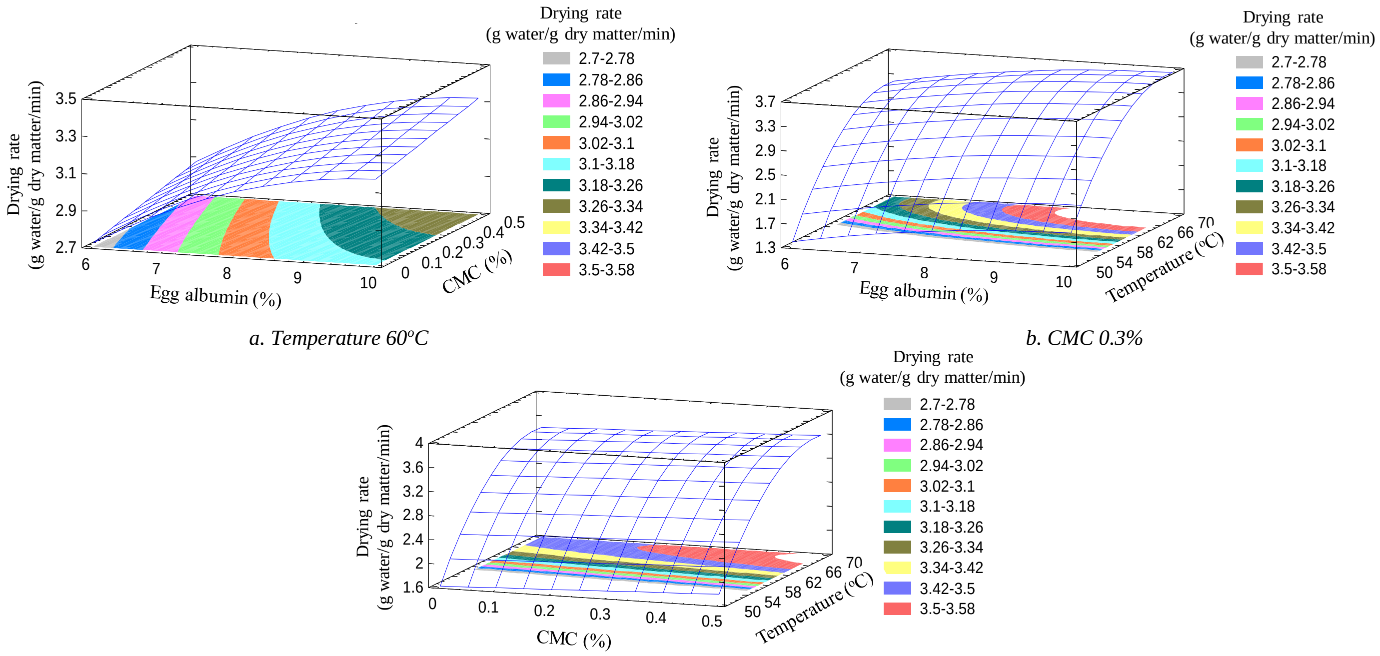


Figure 1 Pareto charts of the effects of process variables on drying rate

The figure shows the length of each bar determined for the relevant effect. All bars that cross the vertical line are statistically significant at the determined level of significance. The results of this analysis again showed that X_3 and its squared interaction have the most important influence on the DR, followed by X_1 and its squared interaction. The CMC content X_2 also affected drying rate but this effect is not as important as X_1 and X_3. The other interactions did not cross the line in the figure, indicating that their influence is meaningless on the DR.

The response surface and contour plot showing the correlation between papaya powder drying rate with albumin ratio, CMC ratio and drying temperature are presented in Figure 2. It is observed that albumin content and drying temperature significantly affected drying rate with the values calculated in the range of 1.32±0.03 to 3.60±0.01 g water/g dry matter/min. The drying rate gradually increased when the drying temperature was higher and the albumin content used was greater, it may be due to an increase in foam content can help enhance the drying rate by promoting surface evaporation. At a constant temperature of 60ºC (Figure 2a), the drying rate showed a clear increase with higher albumin concentration and increased more slowly with the CMC concentration used. Figure 2b and Figure 2c also showed a clear influence of temperature, followed by egg albumin and finally CMC, as evident from the shape of the figure. With the goal of optimizing DR at an optimal value of 3.72 g water/g dry matter/min, the optimal concentration of albumin, CMC and drying temperature are 10%, 0.5% and 68.66ºC, respectively, corresponding to a drying time of 3 hours. The product's surface area increases with the agents to facilitate mass and heat transfer. Higher drying rates are possible under these circumstances **(Djaeni *et al*., 2015)**. **Lewicki (2006)** reported that the porous structure, greater surface area, and enhanced heat transfer rate of foam contribute to a higher nutritional and organoleptic quality as well as an accelerated drying rate. According to **Krasaekoopt and Bhatia (2012)**, the incorporation of air bubbles into foam is a significant factor that influences the rate of drying. Due to the large surface area exposed to the drying air, which ensures quick moisture removal, the drying rate of the foam-mat drying method is comparatively high. The stability of the foam is vital during the drying process; if

it collapses, cellular disruption may ensue, potentially seriously impairing the drying procedure. Tiny bubbles within the foamy mass are exposed to a vast surface area for the purpose of eliminating moisture. The moisture moving through the liquid layers separating the foam bubbles is what causes the rapid drying. According to **Rajkumar *et al*. (2007)**, foaming causes the mass that is drying to become incredibly porous and obedient to the drying of its inner layers. In general, materials in the foam form dry more quickly than those that didnot form the foam. The drying rate rises with increasing foam surface area (**Rajkumar *et al*., 2007**). According to **Osama *et al*. (2022)** the average drying rate was shown to decrease with increasing foam thickness and to increase with drying temperature and albumin concentration.
DR increases with increasing drying temperature, which has the potential to produce quality papaya powder, saving energy and drying costs. **Djaeni *et al*. (2015)** reported that the presence of egg albumin and also the stabilization of CMC can accelerate the DR. The high albumin content used also resulted in a higher drying rate. However, they added quite a high amount of egg white (20%) and 10% methyl cellulose. The improved DR was due to the increased surface area of the foam, increasing the surface area exposed to the drying process, thus increasing the DR. **Sangamithra *et al*. (2015)** reported that muskmelon powder could be foamed using egg albumin as foaming agent (11.59%) and CMC (0.59%) as stabilizer and drying foam at 70ºC gave a DR of 1.005 g/min. Meanwhile, non-foaming powder has a lower drying speed (0.592 g/min) at the same drying temperature.
In the study of tomato foam drying, **Olaniyan *et al*. (2017)** reported that foam stabilizer contributed more to DR, followed by the interaction between foam agent and foam stabilizer. Some previous studies also showed the influence of temperature on foam drying kinetics, they reported a decrease in moisture content during drying time, high drying temperature led to increased moisture diffusion rate and water evaporation on the surface (**Rajkumar *et al*., 2007**; **Thuwapanichayanan *et al*., 2008**).



a. Temperature 60ºC

b. CMC 0.3%

c. Egg albumin 8%

Figure 2 Response surface plot of the influence of variables (foaming agent, foaming stability and drying temperature) on DR

β-carotene

Optimization of β-carotene content from papaya foam-mat drying to form a convenient powder product was carried out. In the case of analysis of variance (ANOVA) on β-carotene content, the results showed that most of the independent variables and their interactions had P-values less than 0.05, indicating a high level of significance, except for X_1X_2 and X_2X_3 interactions (Table 5). The P value of Lack-of-fit is also greater than 0.05 (= 0.08), so the model also fits the data quite well (95% confidence level). The correlation coefficient values R^2 and adjusted R^2 are also quite high (92.21% and 90.62%) and the estimated standard error is small (0.86).

Table 5 Analysis of variance for β-carotene

Source	Sum of Squares	Df	MeanSquare	F-Ratio	P-Value
X_1: Albumin	10.088	1	10.0881	13.50	0.0007
X_2: CMC	3.137	1	3.1371	4.20	0.0469
X_3: Drying temperature	29.956	1	29.956	40.09	0.0000
X_1X_1	16.258	1	16.258	21.76	0.0000
X_1X_2	0.0424	1	0.0424	0.06	0.8127
X_1X_3	4.6152	1	4.615	6.18	0.0171
X_2X_2	6.28412	1	6.284	8.41	0.0060
X_2X_3	0.0098	1	0.0098	0.01	0.9094
X_3X_3	322.86	1	322.86	432.06	0.0000
Lack-of-fit	5.3177	3	1.773	2.37	0.0843
Pureerror	30.638	41	0.747		
Total (corr.)	461.596	53			
R^2 = 92.21%		R^2 (adj. for d.f.) = 90.62%		SEE = 0.86	

The equation of the fitted model is given in Equation 3, with R-squared of 92.2%, R-squared (adjusted for d.f.) of 91% and standard error of est. 0.86.

$$Y_2 = -141.5 + 2.92X_1 + 12.2X_2 + 5.6X_3 - 0.279X_1^2 + 0.03X_1X_3 - 17.32X_2^2 - 0.05X_3^2 \quad (3)$$

Where: Y_2 is β-carotene (μg/g), X_1, X_2 and X_3 are albumin concentration (%), CMC concentration (%) and drying temperature (ºC), respectively.

A Pareto chart of the influence of process variables on β-carotene is presented in Figure 3. The chart shows that factor X_3 (drying temperature) is the most important (bar length is the longest) among the factors affecting β-carotene content, followed by X_1 (albumin) and finally X_2 (CMC).

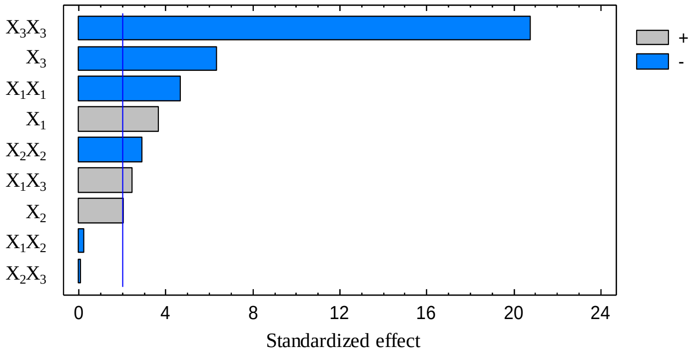


Figure 3 Pareto charts of the effects of process variables on β-carotene

The response surface and contour plots showing the correlation between β-carotene content and albumin, CMC concentration and drying temperature are presented in Figure 4. At constant temperature (Figure 4a), the β-carotene content was high with increasing albumin and CMC, but past the maximum point the content balanced or decreased slightly. Drying temperature clearly affected β-carotene content (Figures 4b and 4c) when CMC and albumin contents were kept constant. Low drying temperatures (50ºC) often require longer drying times to achieve balanced moisture (about 8.5%), so β-carotene destruction easily occurs. At high drying temperatures (70ºC), even shorter drying times. It also could not maintain well β-carotene content due to its heat sensitivity.

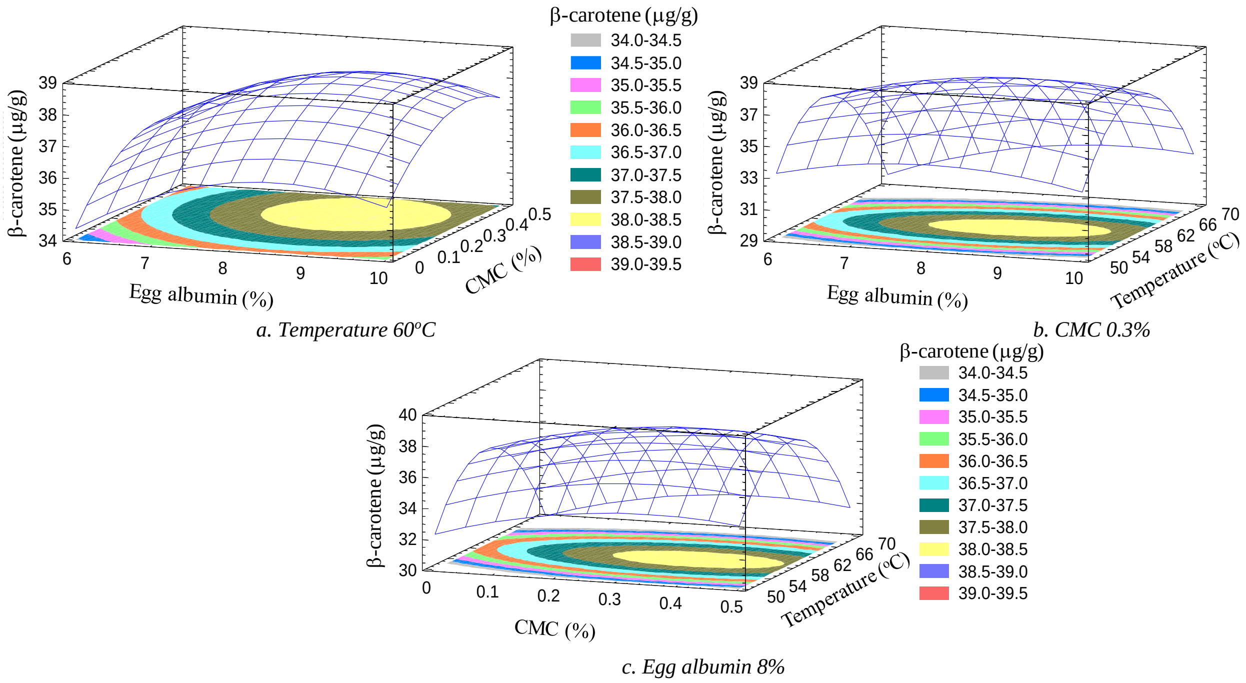


Figure 4 Response surface plot of the influence of variables (foaming agent, foaming stability and drying temperature) on β-carotene

Based on the maximum retention of β-carotene content, the optimal treatment of the foaming agent was found to be 8.5% albumin, 0.35% CMC and drying at 59ºC.The decrease in β-carotene content due to its heat-sensitive nature has been discovered from many previous studies (**Muratore *et al*., 2008; Auisakchaiyoung and Rojanakorn, 2015**), the decomposition of β-carotene occurs due to the impact of high drying temperature for other types of plants.The high carotenoid content was maintained (70 to 93%) when drying mango slices for a short time (3.5 hours) was reported by **Pott *et al*. (2003)**. The photosensitivity, isomerization, and epoxide-forming properties of carotenoids may be the cause of the loss of total carotene **(Mir and Nath, 1993).** The foaming and thermal drying process of the foam mat resulted in minimal to no carotenoid degradation **(Sifat *et al*., 2021).**

Simultaneous optimization of response surfaces

The research results showed that papaya foam drying conditions can be optimized to achieve the highest DR and β-carotene content in papaya powder. RSM was used to determine the optimal values of X_1, X_2 and X_3 to maximize the response variables. The results presented above have determined that to achieve the highest drying rate and β-carotene content, the albumin and CMC content used ranges from 8.5% to 10% and 0.35% to 0.5%, respectively, the optimal temperature between 59ºC and 68.66ºC. Therefore, it is more useful to optimize the two responses DR and β-carotene content to evaluate the effects of multiple variables on these two responses. The DR and β-carotene content models were fitted before optimizing the two responses.

The numerical optimization results showed the desired maximum level (0.9) can be achieved using the optimal values of albumin content, CMC and temperature respectively 9.07%, 0.39% and 62ºC. Under these three conditions, the optimal DR and β-carotene content were determined as 3.41 g water/g dry matter/min and 37.95 µg/g, respectively. Research on foam-mat drying tomato paste by **Hossain *et al*. (2021)** published the optimal concentrations of albumin lower than in this study (7%) and CMC higher (1%) with nearly similar temperatures (60ºC). The verification of optimal values of our study was also performed. With these optimal values put into practice, the DR and β-carotene content in the foam-mat dried papaya powder were determined as 3.5 g water/g dry matter/min and 38.8 µg/g, respectively. The experimental and predicted values are almost identical, only slightly different (from 2.19 to 2.57% < 5%). It was observed that the regression equations Y_1 and Y_2 fitted from this study could be used to create foam-dried papaya powder products with optimal DR and β-carotene content in the sample.

The quality and rehydration rate

Under optimal conditions obtained, the foam-dried papaya powder product (Figure 5) contain water content of about 8-9%, a water activity of 0.35, maintaining the natural color of papaya (L*=63.54; a*=29.12; b*=36.27). The product's fine structure is relatively uniform, as shown from micrograph taken with a scanning electron microscope (SEM) (Figure 6). It can be seen that the powder particles form clusters of particles and clumps that are nearly stuck together, perhaps due to the presence of albumin and CMC. However, adjacent bubbles also appear and the voids are quite uniform, showing that the collapse of the foam structure rarely occurs during drying when using optimal foaming agent concentrations and proper drying temperature.

Figure 5 Foam-mat dried papaya powder obtained from different foaming agent albumin 9.07%, CMC 0.39% and drying temperature at 62ºC

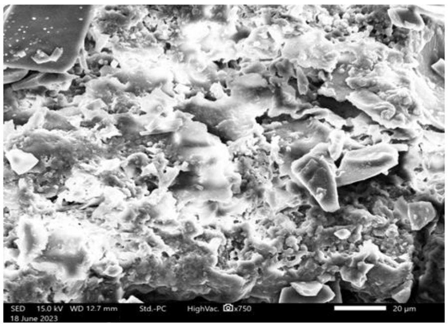


Figure 6 Scanning Electron Microscope image of particles of papaya powder - size 20 μm (x750)

The ability to rehydrate dry material after collection is also considered a quality criterion. The analysis result of the rehydration rate of the foam-dried papaya powder sample was 4.05±0.1. **Belal *et al*. (2023)** have announced that the rehydration rate of tomato powder ranges from 3.22±0.007 and 4.25±0.05, which was positively related to thermal treatment. **Tan and Sulaiman (2020)** also reported that the rehydration rate can increase significantly at temperatures from 60°C to 70°C and in increasing of foaming agents and foam stabilizers concentration. The microstructure of papaya powder (Figure 6) may also be related to the water absorption rate, the foam dried at 62ºC is probably due to its porous structure, allowing water to penetrate deeper.

CONCLUSION

A Box-Behnken statistical experimental design with the RSM has been applied successfully for modelling and optimizing foam mat drying process parameters for papaya. The DR and β-carotene in the foam-mat dried papaya powder was mostly effected by temperature followed by albumin and CMC. The model equations developed in this study are reliable and can be applied to predict the drying process and quality of dried papaya powder on an industrial scale. Foaming agents and foam stabilizers are added with optimal content (albumin 9.07% and CMC 0.39%), drying at 62ºC has been successfully applied in the production of dried foam papaya powder, natural color with powder particles had more porous and granules. The quality and rehydration ratio of the powder are also determined. Foam-dried papaya powder can be used in many food product formulations, helping to provide additional sources of available vitamin A in the diet, reducing vitamin A deficiency in developing countries.

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