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Using response surface methodology to optimize foam-mat drying conditions related to drying rate and β-carotene concentration of orange-fleshed sweet potato powder

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Abstract

Response surface methodology and Box-Behnken design (3 factors and 3 levels) were performed to optimize the effects of different egg albumin contents (5-15%), xanthan gum (0.1-0.5%) and drying temperature (50-70ºC). Drying rate and β-carotene content are indicators observed through 18 experimental runs and 6 repetitions at the center point. Finally, the physical properties such as color, water solubility index, water absorption index and rehydration ratio together with moisture content, water activity and microstructural of OFSP powder were analysed. The total polyphenol content (TPC), DPPH scavenging activity and β-carotene were analysed. Research results revealed that the optimal egg albumin concentration, xanthan gum concentration and drying temperature of 10.73%, 0.33% and 65.48ºC, respectively as foam-mat drying parameters were recorded. From those optimal parameters, the optimal values of drying rate and β-carotene were determined to be 2.34 g water/g dry matter/min (maximize) and 51.82 µg/g (maximize), respectively. Foam-mat dried powder contained low moisture content and water activity, 4.15% and 0.343, respectively, along with water solubility index, water absorption index and rehydration ratio were respectively determined to be 45.87%, 2.36% and 3.97. The color of foam-mat dried OFSP powder was evaluated. According to the findings, the content of β-carotene (48.61±0.5 µg/g) and TPC (2.24±0.04 mgGAE/g) along with antioxidant activity (57.43±1.2%) of OFSP powder products were also determined. SEM analysis of OFSP powder particles at different magnifications showed that they have irregular surface morphology and flake-like structures, different from the structure of powder particles dried by convection drying method, the surface is quite smooth and the structure is intact.

Keywords: foam-mat drying, foaming agents, drying temperatures, chemico-physical properties, optimization

Full length article **Corresponding Author*, e-mail: nmthuy@ctu.edu.vn Doi # https://doi.org/10.62877/31-IJCBS-24-25-19-31

1. Introduction

Sweet potato (*Ipomoea batatas* L.) is a tuber crop with a short growing period, adapted to many different soil types. Sweet potatoes are considered one of the staple foods, playing an important role in the human diet, especially in some underdeveloped countries [1]. Sweet potatoes are a good source of fiber, low in fat and protein but rich in carbohydrates [2], so it can be considered a food with high nutritional value. Many antioxidant compounds are found in sweet potatoes such as phenolic acids, anthocyanins, β-carotene and tocopherol [3, 4]. Among them, orange-fleshed sweet potato (OFSP) is considered a source of high levels of carotenoids (provitamin A) for the human.

Many studies have proposed using OFSP to overcome the problem of vitamin A deficiency that often occurs in poor and developing countries [3, 5], with β-carotene as a component being of main concern. β-carotene is also known as an antioxidant with the ability to prevent

aging processes, prevent cancer, cardiovascular diseases, and increase immunity. In addition, cataracts and macular degeneration can also be slowed down [6, 7]. Thus, consuming orange-fleshed sweet potatoes can be considered an alternative solution to increase nutrient intake. In Vietnam, sweet potatoes are only used for simple processing in households such as steaming, frying, cooking, and only a small amount is fried/dried on an industrial scale. A large output of sweet potatoes has high quality value but has not been fully exploited with a large annual backlog. The shelf life of sweet potatoes in fresh form is very short, only about 5 to 20 days, so they have also been processed into dry form to extend storage time, reduce post-harvest losses and increase economical value of this source.

In food processing techniques, drying is a method that can reduce microbial load, prevent spoilage of products and extend their shelf life [8]. Among the drying methods used, foam-mat drying has been considered a simple drying process since this technique works especially well for foods that are liquid or semi-liquid, temperature-sensitive, viscous, sticky, and have high sugar content [9-12], that cannot be done with other drying methods. With this drying technique, foaming agents and foam stabilizers at different concentrations are used to prepare stable foam mats, followed by a drying process carried out at temperatures around 50-80^{o}C [13, 14]. Foam drying products reduce moisture quickly in a short time, so they are cost-effective and convenient while still maintaining product quality compared to other drying methods such as traditional drying or spray drying. In recent years, foam-mat drying technique has received more attention and has been applied to dry passion fruit aril, fig fruit, peach, magenta leaves and Artemia biomass [11, 12, 15-17]. When yellow sweet potato powder is produced, it not only helps prolong the shelf life of the product, but also creates favorable conditions to include it in the diet in combination with other foods. OFSP powder contains high levels of β-carotene, which will be a rich source of vitamin A, providing good support for human health. However, it is necessary to optimize flour processing conditions to reduce carotenoid loss [18] while achieving the shortest drying time. Drying OFSP in microwaves and hot air was done by Sebben *et al.* [7]. The effects of different drying conditions on the physical properties of sweet potato slices were studied by Afolabi *et al.* [4]. Jakkranuhwat and Kunchansombat [19] studied the effects of foam mat drying conditions on antioxidant activity, phenolics synthesis, anthocyanin content and color of purple-fleshed sweet potato powder. The effects of blanching and foam-mat drying on the physico-chemical properties of white sweet potato inulin were carried out by [20]. However, optimization of the foam-mat drying to create powder from OFSP has not yet been done. Therefore, the goal of this study is to optimize the foaming agent concentration, foam stabilizer and drying temperature to obtain OFSP powder containing high levels of bioactive compounds with short drying time. Finally, product quality was also analyzed (physical and chemical characteristics, antioxidant activity and microstructure), to have a basis for further using products from this research for nutritional food products processing.

2. Materials and methods

2.1 Materials

Orange-fleshed sweet potatoes (OFSP) are harvested at the Farm in Binh Tan district, Vinh Long province, Vietnam. After harvesting, sweet potatoes were cleaned, peeled, analyzed for moisture (MC) and β-carotene content with values of 74.52% and 21.24 µg/g, respectively.

2.2 Box-Behnken Design (BBD) for foam-mat drying

Box-Behnken design (BBD) of response surface methodology (RSM) was used for the study. The level of input variables varied with egg albumin (EA), xanthan gum (XG) concentrations and drying temperature varying between 5 and 15% (w/w), 0.1 and 0.5%. (w/w) and 50 to 70^{o}C, respectively. The low and high levels of each factor were coded as –1 and +1, with 0 being the midpoint (Table 1). The responses in this case are drying rate and β-carotene content. Each response was analyzed in triplicate and reported as the mean.

2.3 Sample preparation and foam-mat drying

200 g of sweet potato was mixed with water at a ratio of 1:2 (w/v), crushed finely for 2 minutes with a blender [11]. Put into 1000 mL beaker, continue adding EA and XG according to the arranged ratio. The mixture was whipped using a mixer (Philips HR3705, 300W, China) at highest speed for 5.8 min [10]. Then the foam mixture is spread out on a stainless-steel tray (100 g sample/tray) with a foam layer thickness of 4 mm. The trays with samples were put into a convection oven (Memmert UN30, Germany), dried at temperature from 50 to 70^{o}C (as arranged) until the final moisture reached about 4-5% (<10%) [19]. The sample continues to be finely ground and sifted through a sieve (particle size about 0.04 mm), recovering a fine powder.

A quadratic polynomial regression equation (Equation 1) was used to describe the fit to the experimental data of all responses.

$$Y = a_o + a_1X_1 + \alpha_2X_2 + a_3X_3 + a_{12}X_1X_2 + a_{13}X_1X_3 + a_{23}X_2X_3 + a_{11}X_1^2 + a_{22}X_2^2 + a_{33}X_3^2 \quad (1)$$

Where: Y is predicted responses (drying rate/β-carotene); a_o is intercept coefficient; a_1, a_2, a_3 are linear terms; a_{11}, a_{22}, a_{33} are quadratic terms; a_{12}, a_{13}, a_{23} are interaction terms and X_1, X_2, X_3 are independent variables.

2.4 Physical analysis

Moisture content (%) was analyzed according to the AOAC [21]. *Water activity* (a_w) was recorded using RotronicHygroPalm HP23-AW-A-SET-40 (USA). *The color values (L*, a* and b*)* were read using a Hunter Lab Colorimeter (Color Flex, USA). *Drying rate (DR)* was calculated according to the formula presented in the publication of Thuy *et al.* [22]. *Water solubility index (WSI)* and *water absorption index (WAI)* were calculated according to Grabowski *et al.* [23]. *Rehydration ratio* was recorded following the method of Kadam *et al.* [24]. The microstructure of the foam-mat dried samples was observed using Scanning Electron Microscopy (Hitachi S-4800, Japan) at magnifications 200x, 2000x and 5000x.

2.5 Chemical analysis

β-carotene content (µg/g) was analyzed using the method of Fikselová *et al.* [25]. *Total polyphenol content (TPC)* was determined according to the Folin–Ciocalteau method [26]. *DPPH (%)* of the product was analyzed based on 1,1-diphenyl 2-picrylhyorazyl (DPPH) free radical scavenging activity [27].

2.6 Statistical analysis

Statgraphic Centurion software version XV.I (USA) was used to analyze regression and analysis of variance (ANOVA), calibrated the models expressed according to the formula and test the statistical significance of the model terms. The F value was determined to test the significance of all fitted equations at the 5% significance level. The relationship between responses and factors was determined and the optimal conditions and suitable equations were obtained.

3. Results and Discussions

3.1 Effect of foaming and drying conditions on drying rate and β-carotene content (according to Box-Behnken design)

The results of calculating drying rate and analyzing β-carotene content are presented in Table 2. It was observed that drying rate and β-carotene change depending on foam-mat drying conditions, including EA concentration, XG concentration and drying temperature. Drying rate reached the highest value of 2.482 g water/g dry matter/min when EA, XG and drying temperature were 10%, 0.5% and 70°C, respectively. Meanwhile, the lowest DR value was observed (1.008 g water/g dry matter/min) when EA and XG used 5% and 0.3%, respectively at drying temperature of 50°C. Similarly, under the same conditions, β-carotene reached the lowest value of 38.63 µg/g (EA and XG used 5% and 0.3%, drying temperature at 50°C) and the highest value of 52.90 µg/g when EA, XG and drying temperature are 10%, 0.3% and 60°C, respectively.

Drying rate increases as the drying temperature increases and leads to a decrease in drying time. This may be due to the increased rate of movement and evaporation of moisture on the surface of the product. Research on the effects of temperature and drying time on the β-carotene content of osmotic mayongchit products, Langkapin and Oupathumpanont [28] had also shown that the highest drying temperature (70°C) gives the highest drying rate. Some previous authors showed similar effect of air drying temperatures on drying rate [29, 30]. Besides, drying temperature also significantly affects the decomposition of β-carotene. Demiray and Tulek [31] reported that drying temperature significantly affected the degradation of β-carotene in carrot slices. Ihns *et al.* [32] also reported similar results on β-carotene degradation during drying of two apricot varieties.

3.2 ANOVA results, regression model and pareto chart for drying rate and β-carotene

From the ANOVA table (Table 3), it can be seen that both drying rate and β-carotene have 7 effects with P values less than 0.05, confirming they are significantly different from zero at the 95.0% confidence level. In addition, observing the correlation between drying rate and independent variables, we can see linear coefficients (X_1, X_2, X_3), square coefficients (X_1X_1, X_2X_2, X_3X_3) and interaction coefficients. (X_2X_3) has a significant influence on the drying rate (P-values are all less than 0.05). Meanwhile, interactions X_1X_2, X_1X_3 do not significantly affect drying rate (P values greater than 0.05).

The correlation between β-carotene and the independent variables again showed that, the linear coefficients, square coefficients and interaction coefficient X_1X_3 all affect β-carotene (P-value<0.05), while interactions X_1X_2 and X_2X_3 do not have meaningful influence (P-value >0.05).

The R-Squared statistics of both fitted models explained 96.52% and 96.97% of the variation in drying rate and β-carotene, respectively. Adjusted R-squared, which is considered more appropriate for comparing models with different numbers of independent variables, are 95.81% (drying rate) and 96.35% (β-carotene). The standard error of the estimate obtained 0.091 (for the drying rate model) and 0.95 (for β-carotene). Since the P-values of lack-of-fit in the ANOVA table for drying rate (0.052) and β-carotene (0.722) are greater than 0.05, the models seem to fit the observed data at the 95.0% confidence level.

From the above analysis, the effects that did not significantly affect (P-value>0.05) on drying rate (X_1X_2, X_1X_3) and β-carotene (X_1X_2, X_2X_3) were removed from the model. New models (Y_1 and Y_2) were established corresponding for drying rate (Equation 2) (R^2=96.50%, R^2adj.=95.97%) and β-carotene (Equation 3) (R^2=96.85%, R^2adj.=96.37 %).

$$Y_1 = -10.777 + 0.083X_1 - 0.334X_2 + 0.346X_3 - 0.003X_1^2 - 1.885X_2^2 + 0.028X_2X_3 - 0.002X_3^2 \quad (2)$$

$$Y_2 = -187.33 + 5.34X_1 + 56.18X_2 + 6.62X_3 - 0.22X_1^2 - 0.01X_1X_3 - 90.10X_2^2 - 0.05X_3^2 \quad (3)$$

Where, Y_1 is drying rate (g water/g dry matter/min), Y_2 is β-carotene (µg/g), X_1 is EA concentration (%); X_2 is XG concentration (%); X_3 is drying temperature (°C).

Pareto charts for drying rate and β-carotene are presented in Figure 1 also showed the impact of the variables (X_1, X_2, X_3) on drying rate and β-carotene. Pareto chart for drying rate (Figure 1a) showed that the effects bars X_1, X_2, X_3, X_1X_1, X_2X_2, X_3X_3 and X_2X_3 cross the reference line so they are statistically significant (5% level). From this figure it can be clearly seen that drying time has the most important influence on drying rate.

Similarly, the pareto chart for β-carotene (Figure 1b) showed that the effects bars X_1X_2 and X_2X_3 do not cross the reference line, so they are not statistically significant at 5% level. In this case, the squared interactions of X_1, X_2 and X_3 all affect the β-carotene content.

3.3 Response surface plots and simultaneous optimization

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

The influence of the factors and their interactions on the drying rate, through response surface plots, is presented in Figure 2. When fixing the drying temperature at 60°C (Figure 2a) and using an EA concentration increasing from 5 to 15%, the drying rate increased in the range of 1.6 to 2 g water/g dry matter/min. In addition, increasing XG content from 0.1 to 0.5% also increased drying rate from 1.8 to 2.2 g water/g dry matter/min. Djaeni *et al.* [33] also showed that the drying rate also increased with the added albumin content, proportionally. The increase in foam concentration increases drying rate possibly because albumin forms a porous structure (foam), the increased foam volume after whipping also increases the contact surface area, which makes the drying rate faster. From there, moisture diffuses to the surface during the drying is maintained at a high level.

However, increasing the egg albumin concentration excessively will cause an overall decrease in foaming ability,

precisely because high protein content also increases the viscosity of the solution, thus not creating good conditions for the amount of air are combined at the interface. Kadam and Balasubramanian [34] found that the EA content increased up to 15% could enhance the drying process but then had a decreasing trend. XG is a foam stabilizer that helps build the right structure and prevents foam breakdown, accelerating the drying process. An increase in XG concentration increases the stability of the foam structure, facilitating faster moisture mass transfer. The foam structure stability facilitates the free water transfer into dry air [35]. When fixing XG concentration at 0.3% (Figure 2b) and EA concentration used at 10% (Figure 2c), it was found that drying temperature increased drying rate significantly from about 1.0 to 2.6 g water/g dry matter/min. High drying temperatures caused the moisture rate to decrease faster, this is due to the supply rate of hot air to the drying material, causing the moisture movement speed also increasing [36]. Furthermore, the shortening of drying time as drying temperature increases is thought to be due to increased heat energy, which increases the speed of movement of water molecules in the food food [37]. Furthermore, increased temperature has caused the material to lose moisture faster, so drying time is shortened [38]. The results obtained from this study are also quite similar to many findings reported in some previous literatures. The authors suggested that the higher temperature increased the heat difference [39-41]. To achieve the optimal, maximize drying rate of 2.508 g water/g dry matter/min, the optimal values of EA concentration and XG concentration used to be 13.41% and 0.423% at the optimal drying temperature of 70^{o}C.

3.3.2 β-carotene (µg/g)

Response surface plots showing the influence of factors and their interactions on β-carotene content are shown in Figure 3. At a constant drying temperature of 60^{o}C (Figure 3a), when EA concentration changes from 5% to 10.43%, the β-carotene content increases from 37.23 to 43.85 µg/g. However, when past this optimal point, β-carotene content tends to decrease. Besides, β-carotene content tends to increase (39.29 to 48.05 µg/g) when increasing XG concentration from 0.1 to 0.31% and tends to decrease slightly to 44.85 µg/g when XG concentration increases to 0.5%. When fixing the XG concentration used at 0.3% (Figure 3b), the EA concentration used increased from 5 to 10.79% and the drying temperature increased from 50^{o}C to 60.85^{o}C, the β-carotene content also increased but then tended to decrease. Similarly, when fixing EA concentration used to 10% (Figure 3c), the β-carotene content of the powder also increased when increasing XG concentration used from 0 to 0.31% and drying temperature increased from 50 to 61.58^{o}C. However, β-carotene content tends to decrease slightly when it exceeds this optimal level. Several previous studies have published that β-carotene content of foam mat dried powder increases with increasing albumin concentration [9, 42, 43]. This result is due to the increase in surface area with increasing foaming concentration. Reis *et al.* [44] also showed that egg albumin (when used as a foaming agent) demonstrated the ability to retain biological activity. XG is a natural polysaccharide and an important industrial biofilm-forming agent, a complex of proteins and polysaccharides capable of encapsulating biologically active substances [45] there by increasing XG concentrations contributed to avoiding loss of β-carotene content during drying. In addition, the stabilized foam structure improved the heat transfer rate, making the foam dry faster and more efficiently and limiting the loss of β-carotene content. However, when the concentrations of EA and XG increase too high, the β-carotene content tends to decrease, possibly due to the increase in contact surface area, so β-carotene easily comes into contact with air oxygen and light, leads to the breakdown of β-carotene. Some studies have also shown that drying temperatures from 60 to 65^{o}C help to maintain the highest β-carotene content [24, 42, 46]. At drying temperatures lower than the optimal temperature, the drying time is prolonged, then β-carotene is exposed to light and oxygen in the air longer, so the loss increases due to oxidation. Betoret *et al.* [47] reported that carotenoids are easily degraded when exposed to light and heat. Besides, β-carotene also decreases when drying temperature increases due to its heat-sensitive nature. This is also consistent with the report of Muratore *et al.* [48] and Auisakchaiyoung and Rojanakorn [49], the degradation of β-carotene is due to drying temperature in Gac aril and cherry tomato, respectively. Based on the maximum retention of β-carotene content (52.72 µg/g), the optimal foaming agents were found to be 10.43% EA, 0.31% XG and drying temperature at 61.5^{o}C.

3.3.3 Simultaneous optimization

From the results obtained from individually optimizing the dependent variables of drying rate and β-carotene from the optimal values of the independent variables (EA, XG and drying temperature), the obtained results showed that the optimization parameters are slightly different. For the optimal contents of EA, XG and drying temperatures ranged from 10.43 to 13.41%, 0.31 to 0.42% and 61.5 to 70^{o}C, respectively. Therefore, optimizing two responses simultaneously is more useful when it is necessary to evaluate the impact of multiple variables on the responses. In addition, simultaneous optimization of multiple response surfaces can reduce energy costs. The results presented in Table 4 show the optimal parameters (independent variables) of the OFSP foam-mat drying to obtain the optimal values of the dependent variables (drying rate, β-carotene). The optimal parameters of the OFSP foam-mat drying are obtained, EA concentration and XG used of 10.73% and 0.33%, respectively, at a drying temperature of 65.48^{o}C. From those optimal parameters, the optimal values of drying rate and β-carotene were determined to be 2.34 g water/g dry matter/min (maximize) and 51.82 µg/g (maximize). Research results by Brar *et al.* [17] also reported that the temperature of 65^{o}C for the foam-mat drying was considered the optimal temperature for most dried peach products. Verification of predicted and actual values from optimal parameters was also performed. By using the optimal parameters of independent variables for the OFSP foam-mat drying, the results showed that the predicted value and actual value had only a small difference (1.06% and 3.94% for drying rate and β-carotene content), within acceptable limits (<5%).

Table 1: Values of experimental design variables

Variables	Codes	Level of variables		
		–1	0	+1
Egg albumin (%)	X_1	5	10	15
Xanthan gum (%)	X_2	0.1	0.3	0.5
Dying temperature (°C)	X_3	50	60	70

Table 2: Effects of EA, XG concentration and drying temperature (designed according to Box-Behnken) on drying rate and β-carotene

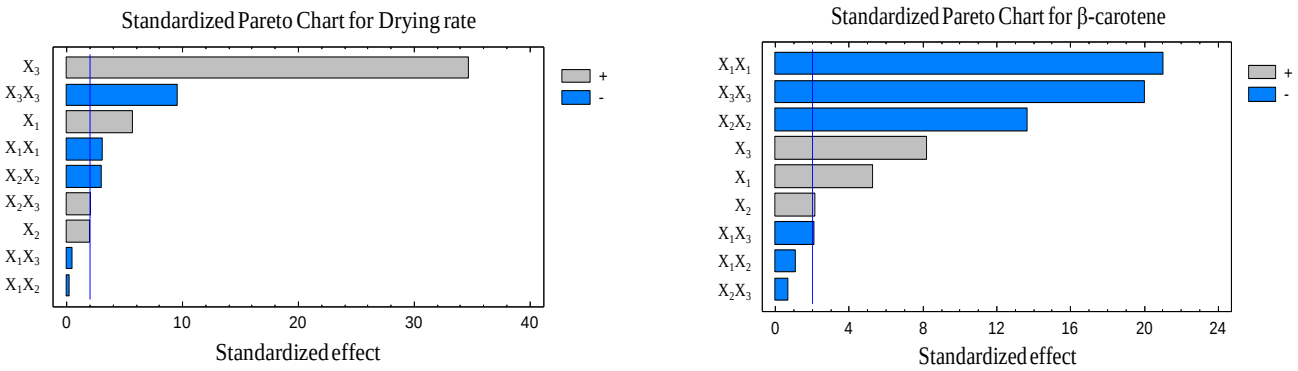
No.	Coded values			Actual values			Drying rate (g water/g dry matter/min)	β-carotene (µg/g)
	X_1	X_2	X_3	EA (%)	XG (%)	Drying temp. (°C)		
1	0	0	0	10	0.3	60	1.937±0.073	52.30±1.01
2	+1	+1	0	15	0.5	60	2.057±0.041	44.44±0.71
3	0	0	0	10	0.3	60	1.996±0.029	52.85±0.93
4	–1	–1	0	5	0.1	60	1.698±0.217	41.75±1.05
5	0	–1	–1	10	0.1	50	1.068±0.017	41.19±1.21
6	0	0	0	10	0.3	60	2.084±0.049	52.33±1.52
7	+1	–1	0	15	0.1	60	2.024±0.015	44.27±1.11
8	0	0	0	10	0.3	60	2.085±0.136	52.78±0.82
9	0	0	0	10	0.3	60	2.046±0.062	52.12±1.09
10	0	+1	–1	10	0.5	50	1.065±0.048	42.49±0.34
11	–1	0	–1	5	0.3	50	1.008±0.009	38.63±1.54
12	0	0	0	10	0.3	60	2.070±0.015	52.90±0.58
13	0	+1	+1	10	0.5	70	2.482±0.091	45.74±0.09
14	–1	0	+1	5	0.3	70	2.318±0.080	42.59±1.23
15	+1	0	–1	15	0.3	50	1.142±0.006	42.02±0.97
16	–1	+1	0	5	0.5	60	1.753±0.195	43.14±0.80
17	0	–1	+1	10	0.1	70	2.264±0.087	45.20±0.76
18	+1	0	+1	15	0.3	70	2.403±0.048	43.64±1.00

Mean±STD, temp: temperature

Table 3: ANOVA results of the quadratic regression model for optimization of drying rate and β-carotene of OFSP foam-mat drying

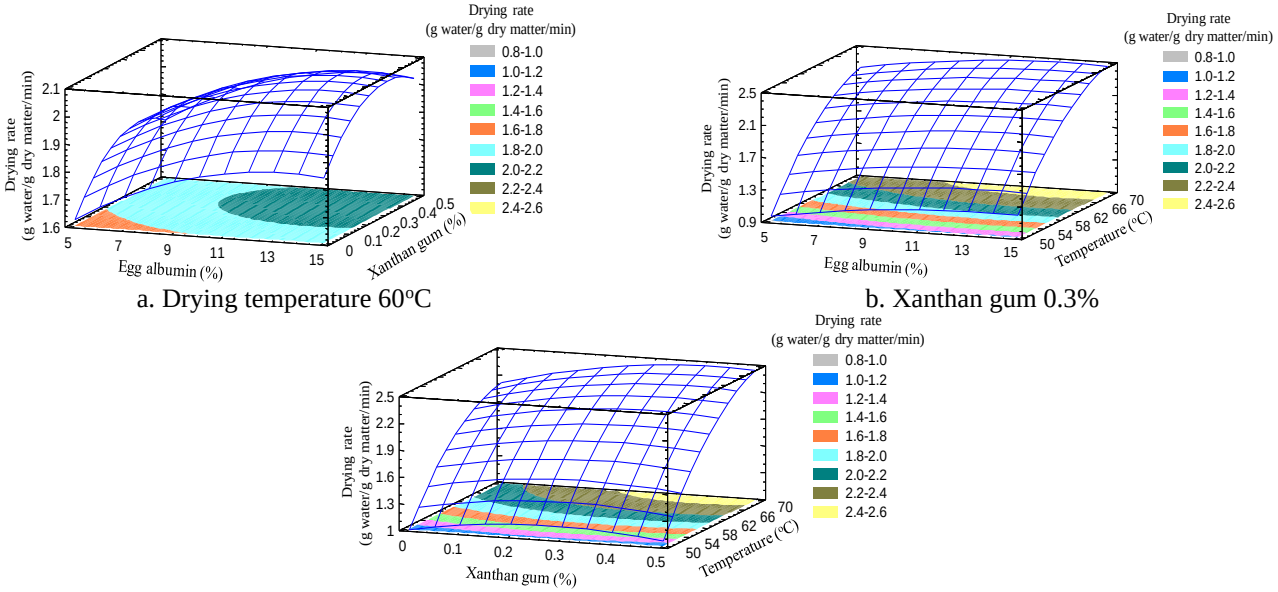
Source	Df	Drying rate			β-carotene		
		Sum of Squares	F-ratio	P-value	Sum of Squares	F-ratio	P-value
Linear							
X_1: EA	1	0.2697	32.25	0.0000*	25.54	28.04	0.0000*
X_2: XG	1	0.0347	4.15	0.0480*	4.31	4.73	0.0355*
X_3: Drying temperature	1	10.0738	1204.87	0.0000*	61.86	67.90	0.0000*
Square							
X_1X_1	1	0.0790	9.44	0.0038*	402.24	441.53	0.0000*
X_2X_2	1	0.0745	8.91	0.0048*	170.04	186.65	0.0000*
X_3X_3	1	0.7598	90.88	0.0000*	365.51	401.21	0.0000*
Interaction							
X_1X_2	1	0.0004	0.04	0.8384	1.12	1.23	0.2748
X_1X_3	1	0.0018	0.21	0.6495	4.13	4.53	0.0393*
X_2X_3	1	0.0365	4.37	0.0429*	0.44	0.48	0.4925
Lack-of-fit	3	0.0701	2.79	0.0522^{ns}	1.22	0.45	0.7219^{ns}
Pure error	41	0.3428			37.35		
Total (corr.)	53	11.8738			1273.29		
R^2		96.52%			96.97%		
R^2 (adj. for d.f.)		95.81%			96.35%		
Standard Error of Est.		0.091			0.95		

*****Significant at the 5% level, ^{ns}Lack-of-fit is not significant at P>0.05.



a. Drying rate b. β-carotene

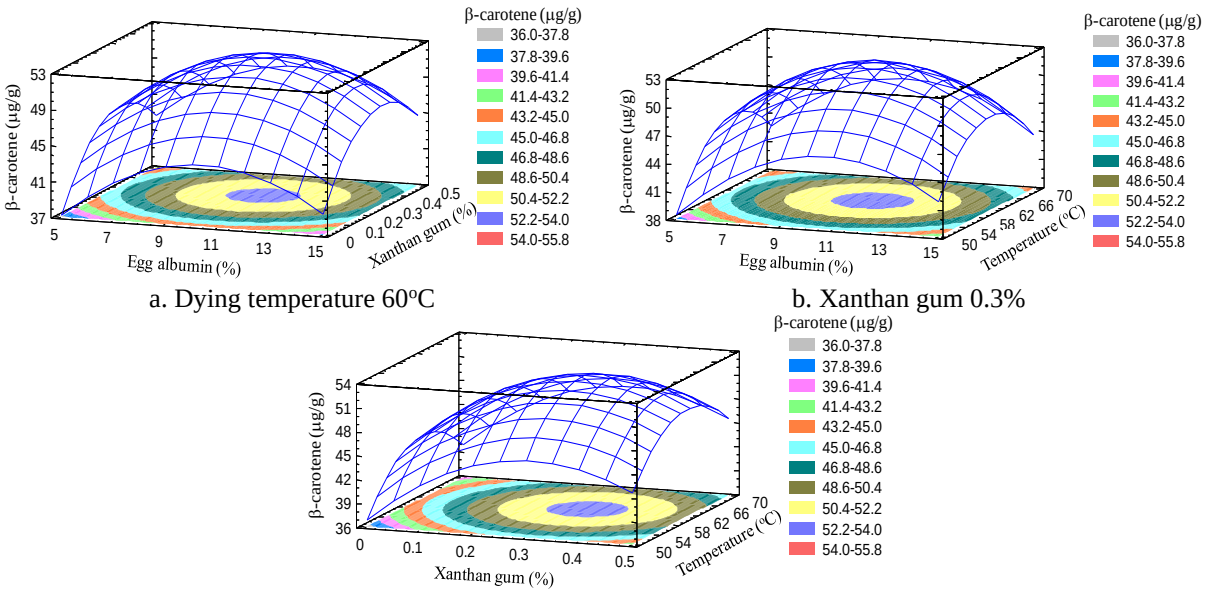
Figure 1: Pareto chart of the effects of EA, XG and drying temperature on the following parameters: a. Drying rate and b. β-carotene



a. Drying temperature 60°C b. Xanthan gum 0.3%

c. Egg albumin 10%

Figure 2: Response surface graph displayed the influence of factors and their interactions on drying rate: a. drying temperature 60°C, b. XG 0.3%, c. EA 10%



a. Dying temperature 60°C

b. Xanthan gum 0.3%

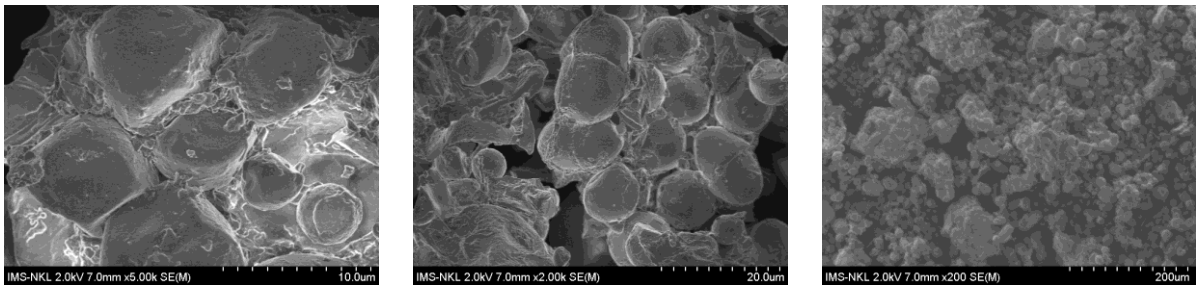
c. Egg albumin 10%

Figure 3: Response surface graph displayed the influence of factors and their interactions on β-carotene: a. drying temperature 60°C, b. XG 0.3%, c. EA 10%

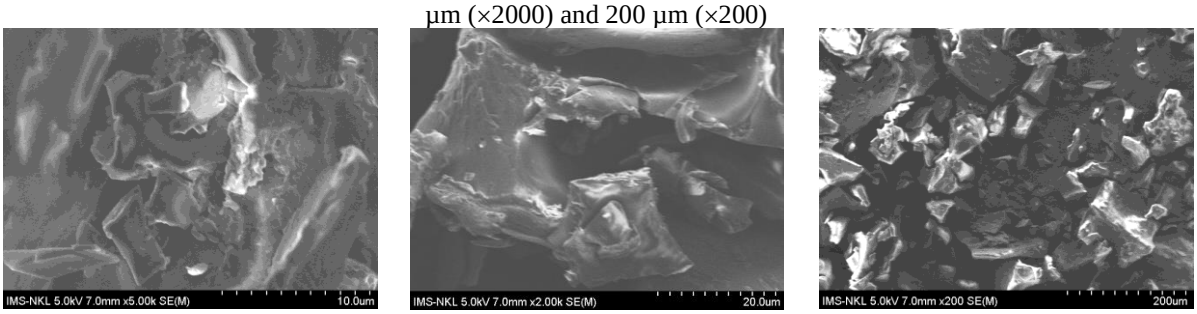
Table 4: Optimal parameters for OFSP foam-mat drying based on dependent variables (drying rate, β-carotene) and verification

	Optimum process parameters			**Dependent variables**	
	EA (%)	XG (%)	Drying temperature (°C)	Drying rate (g warter/g dry matter/min)	β-carotene (µg/g)
Predicted value	10.73	0.33	65.48	2.34	51.82
Actual value				2.366±0.08*	49.78±0.92

*Mean±STD



a. OFSP flour particles dried using convection drying method after grinding, particle size 10 µm (×5000), 20 µm (×2000) and 200 µm (×200)



b. OFSP flour particles dried using foam-mat drying method after grinding, particle size 10 µm (×5000), 20 µm (×2000) and 200 µm (×200)

Figure 4: Scanning electron micrograph of OFSP flour samples dried using a. Convection drying and b. Foam-mat drying

Figure 5: Foam-mat dried OFSP powder

3.3.4 Scanning electron micrograph (SEM)

Morphological characteristics of foam-dried OFSP Morphological characteristics of foam-dried OFSP powder particles (obtained from this study) were compared with conventional convection-dried powder samples from OFSP raw materials (according to the method of Thuy *et al.* [50]). SEM images were observed at magnifications x5000, x2000 and x200 (Figure 4). From these SEM images, it was observed that OFSP powder particles by conventional convection drying method (Figure 4a) have different sizes, their shapes are mainly oval and polygonal, the surface is quite smooth and the structure intact. Meanwhile, the powder particles from the foam-mat drying (Figure 4b) have irregular shapes, their size are large, the particles are broken, look like broken glass, and other particles have scaly structure. These differences in structure compared to conventional dried powder granules may be due to the voids left after the foam is dried, increases the porosity of dry foaming powder. Similar morphology have also been reported from previous studies [17], respectively for the foam drying of yacon juice, blueberry and peach juices. SEM images show that the morphological characteristics of powder particles are affected by the hot-air drying temperature [38, 51]. As the drying air temperature increased, the porosity of the powder structure also increased.

3.4 Product quality of foam-mat OFSP powder

Optimal foam drying parameters (EA, XG and drying temperature) were applied for the OFSP foam-mat drying (Figure 5). With the shortened drying time (3.5 hrs), the powder still maintains its beautiful bright color (close to natural). Bioactive compounds such as β-carotene and total polyphenol still maintain good levels (48.61±0.5 µg/g and 2.24±0.04 mgGAE/g, respectively), along with high antioxidant activity (57.43±1.2%). OFSP foam-mat powder also contains low moisture (4.15%) and a_w (0.34), which is very convenient for storage. Some physical properties, specifically, the water solubility index (WSI), water absorption index (WAI) and rehydration ratio (RR) were quantified to be 45.87%, 2.36% and 3.97, respectively.

Once strategies to control vitamin A deficiency are identified, in addition to vitamin A supplementation, dietary diversification and increased intake of foods containing this vitamin should be implemented. Food products made from OFSP will have the potential to contribute to the control of vitamin A malnutrition in many countries, especially underdeveloped and developing countries with large resources of this raw material.

4. Conclusions

A Box-Behnken design with the RSM has been applied successfully for optimization of foam-mat drying parameters for OFSP. Drying air temperature and foaming agents had direct effect on drying rate and β-carotene, which was mostly effected by temperature followed by egg albumin and xanthan gum. The model equations established from the obtained data are reliable and can be applied to predict the drying process and quality of foam-mat dried OFSP powder on industrial scale. Foaming agents can be added with optimal content (EA 10.73% and XG 0.33%). The optimum drying temperature of 65.5^{o}C has been successfully applied in the production of foam-mat dried OFSP powder. OFSP powder can be used in processing a number of products such as noodles, pasta, vermicelli, bread, nutritional soups, etc. to increase nutritional ingredients/bioactive compounds, color adding and enhance antioxidant activity. The consumption of products prepared from dried OFSP powder will play an important role in developing countries, based on viable food and sustaining a long-term strategy. Developing this activity will improve vitamin A deficiency in children and the whole community.

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