Optimization of Foam Properties and Evaluation of the Drying Temperature Effects on the Foam-Mat Drying of Pasta Sauce

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ABSTRACT

Pasta is a convenient and ready-to-cook meal usually served with sauce. Therefore, this research aimed to explore the optimal parameters for foaming and drying through the foam-mat drying method, intending to achieve superior foam properties and convert pasta sauce into powdered form. The Central Composite Design methodology was employed to ascertain the influence of four independent variables, namely egg white concentration, CMC concentration, water-to-pasta sauce ratio, and whipping time, on the properties of the foam. The drying conditions were orchestrated using a completely randomized design with a single factor comprising three levels, denoting drying temperatures of 50, 60, and 70 °C. The results showed that heightened egg white concentration, water-to-sauce ratio, and whipping time correlated positively with expansion volume and inversely affected foam density as well as drainage volume. Meanwhile, elevated CMC concentration exhibited a diminishing impact on expansion volume with increase in foam density and drainage volume. The optimized conditions conducive to the generation of superior foam properties were 8.99% egg white concentration, 0.1% CMC concentration, 0.54:1 ratio of water to pasta sauce, and 5 minutes of whipping time. The higher drying temperature resulted in lower moisture content, , WAI (water absorption index), and hygroscopicity of pasta sauce powder, with an increase in WSI (water solubility index) and color (lightness). The most favorable drying temperature was determined to be 60 °C, which led to a pasta sauce powder of 7.67% moisture content, 0.21, WAI 8.55 g/g, WSI 0.53%, hygroscopicity 5.65% and color (L 57.21, a 13.83, and b 16.01).

Keywords: Foam-mat drying; foam properties; pasta sauce

INTRODUCTION

Pasta is a staple food in many countries globally, valued for its ease of preparation, delicious taste, and impressive shelf life (Nilusha et al., 2019). It is usually served with pasta sauce, and instant wet sauce condiments are predominantly available in the market. These condiments have inherent downsides, such as short shelf life, bulky, considerable transportation cost, and the tendency to experience an increase in water activity during storage. The increased value is detrimental and can potentially promote the growth

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of microorganisms and other degradation reactions (Meikapasa, 2016). Addressing these challenges involves considering drying methods as a practical solution. Efforts to prolong shelf life, maintain quality, and facilitate the distribution and use of pasta sauce can be effectively achieved by strategically applying diverse drying methods.

One of the viable methods applicable to pasta sauce is foam-mat drying. It involves incorporating foaming and stabilizing agents into the liquid food, followed by drying with hot air (Abbasi and Azizpour, 2016). This method has several advantages, such as cost-effectiveness, streamlined processing, and reduced drying time (Febrianto et al., 2012). Particularly valuable is its ability to process difficult-to-dry materials while producing end products that maintain positive attributes, including the retention of volatile compounds (Kadam et al., 2012). The selection and concentration of foaming agents influence the effectiveness of foam-mat drying. However, common choices for these agents and stabilizers include egg whites and CMC (Hardy & Jideani, 2015).

Previous research extensively explored the effects of various factors on foam-mat drying outcomes for different food products. These factors include the type and concentration of foaming agents, foaming conditions, and drying parameters. For instance, Poonnakasem (2021) achieved optimal characteristics of chili sauce powder by experimenting using 6% egg white as a foaming agent, dried at a temperature of 80 °C. Similarly, the production of tomato powder with a combination of 7% egg white and 1% CMC as foaming agents and stabilizers, at a drying temperature of 60 °C, yielded excellent results (Hossain et al., 2021). Hamzeh et al. (2019) reported that an increase in drying temperature tends to reduce the moisture content, , and oil absorption of shrimp powder. Hariyadi (2019) stated that the optimal operating conditions for tomato extract powder involve using 5% dextrin and albumin, dried at 70 °C for 0.92 hours with a thickness of 2 mm. The production of guava powder using 0.8% CMC and egg white, mixed for 10 minutes, and dried at a temperature of 60 °C, thereby producing a thickness of 4 mm, resulted in the best characteristics (Wadia et al., 2020). In the research by Javed et al. (2018), the optimal foaming conditions for producing the best tomato powder are 10% egg white and a whipping time of 5 minutes. Drying cherry foam at 65 °C yielded the highest solubility, pH, and total acidity while drying time and browning index decreased with increasing temperature (Abbasi & Azizpour, 2016). Sifat et al. (2021) reported the significant influence of egg white concentration and whipping time on the foam characteristics of plum powder produced through foam-mat drying. Adjusting these parameters led to the production of tomato sauce with distinct foam properties such as low density, viscosity, and high expansion (Afifah et al., 2022).

There is a gap in research regarding the optimization of foam properties and the influence of temperature in using the foam-mat drying method for pasta sauce products. In order to address this gap, the core aim of this research was to determine the optimal operational conditions for foaming and the ideal drying temperature. This dual approach was undertaken to obtain enhanced foam properties and to produce top-tier dried pasta sauce powder using the foam-mat drying method.

METHODS

Material

The ingredients for preparing pasta sauce included tomato paste (Wilmond, Zhejiang Ju Zhen

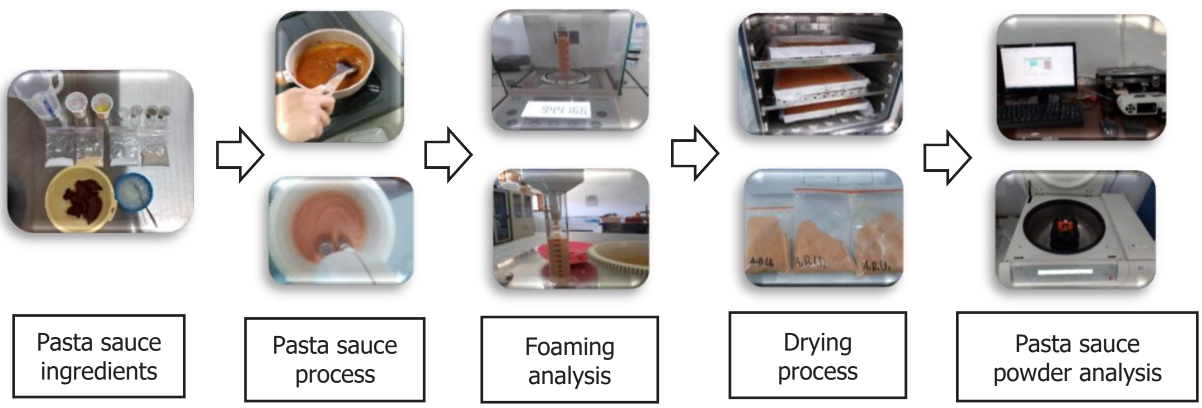

Figure 1. General schematic of experiment

Yuan Foodstuffs Co., Ltd. Dasha Industrial Section, Longquan, Zhejiang, China), garlic, onion, white pepper (PT. Gunacipta Multirasa, Indonesia), salt (PT. Sidola, Indonesia), powdered oregano leaves (PT. Hoka Jaya Internasional, Indonesia), vinegar, and xanthan gum (manufactured by Fufeng, China). The condiments used in the foaming process are chicken egg white and carboxymethyl cellulose (CMC) (PT. Gunacipta Multirasa, Indonesia).

Sample Preparation

Pasta sauce was prepared by blending all the ingredients according to the following composition 4% garlic and onion, 6% salt, 1.5% white pepper, 1% oregano, 2% xanthan gum, 1% vinegar, and water twice the weight of the tomato paste. These percentages were all determined based on the weight of the tomato paste itself. The resulting mixture was then cooked until homogeneous, and this typically lasted for ±5 minutes. The foaming process was carried out by whipping all ingredients, which were beaten using a Philips hand mixer HR1552 set at speed 3. The quantities and whipping time were determined in accordance with the experimental design in Table 2. Furthermore, 300 g of the resulting foamed pasta sauce was evenly spread on a tray measuring 60x40 cm in preparation for the drying phase. Drying was accomplished using a tray-type dryer (Memmert UFB500), operated at 50, 60, and 70°C specified treatment temperatures and maintained for 20 hours. After it was dried, pasta sauce was ground using a PHILIPS Blender Plastic 2 Liter HR2115 and passed through a 20-mesh sieve to ensure a consistent texture.

Experimental Design and Statistical Analysis

This research aimed to obtain dried pasta sauce with optimal physicochemical properties. This involved a rapid drying process using foam and precise temperature optimization to attain this objective. The Stat-Ease Design Expert 7.0 software was used to fine-tune the conditions for pasta sauce foaming. This software employed a face-centered central composite design, resulting in 30 experimental runs. The purpose of these runs was to systematically investigate the influence of four independent variables (egg white, CMC concentration, water-to-sauce ratio, and whipping time) on various foam properties. The assessment of these attributes encompassed three response variables, namely foam density (g/mL) and expansion, including drainage volume (mL). The central point of the experimental design was repeated six times to determine the productivity of the method. A second-order polynomial equation was used to analyze the experimental data for each independent variable, as stated in Equation (1). Furthermore, it facilitated a comprehensive understanding of the intricate relationships between the variables and the resulting foam properties.

$$Y_k = \beta_{k0} + \sum_{i=1}^{4} \beta_{ki} X_i + \sum_{i=1}^{4} \beta_{kii} X_i^2 + \sum_{i=1}^{4} \beta_{kij} X_i X_j \quad (1)$$

The response variable, denoted as Yk, encompasses three distinct aspects, namely Y1, Y2, and Y3, representing foam density, expansion, and drainage volume, respectively. The independent variables are depicted as Xi and Xj, where i=1,2,3,4 is also associated with A, B, C, and D, denoting egg white, CMC, water-to-sauce ratio, and whipping time. Furthermore, βk0, βki, βkii, and βkij depict the constant, linear, quadratic, and interaction coefficients, respectively (Azizpour et al., 2014). The codes and actual values of each independent variable at various levels are shown in Table 1. Symbols A, B, C, and D represent egg white concentration (% w/w of pasta sauce), CMC concentration (% w/w of pasta sauce), water-to-sauce ratio (relative to 1 part of pasta sauce), and whipping time (minutes). The layout of the experimental design using the Central Composite Design (CCD) is shown in Table 2.

Regression analysis and ANOVA of each response were used to assess the model fit with the experimental data and determine the statistical significance of parameters represented in Equation (1). Model

Table 1. Codes and actual values of independent variables at various levels

Name	Symbol	Unit	Variable Level		
			-1	0	+1
Egg White	A	%	3	6	9
CMC	B	%	0.1	0.2	0.3
Water-to-sauce-ratio	C	-	0.5	0.75	1
Whipping time	D	Minute	2	3.5	5

Table 2. Central composite experimental design

Run	A: Egg white (%)	B: CMC (%)	C: Water-to-sauce ratio	D: Whipping time (minute)
1	9	0.2	0.75	3.5
2	9	0.1	1	5
3	3	0.3	1	2
4	9	0.1	0.5	2
5	6	0.2	0.75	3.5
6	9	0.1	1	2
7	6	0.2	0.75	3.5
8	3	0.1	0.5	5
9	9	0.1	0.5	5
10	3	0.1	1	2
11	6	0.1	0.75	3.5
12	3	0.2	0.75	3.5
13	6	0.2	1	3.5
14	6	0.2	0.75	5
15	3	0.3	0.5	2
16	9	0.3	0.5	5
17	9	0.3	1	2
18	3	0.3	1	5
19	6	0.2	0.75	3.5
20	3	0.1	0.5	2
21	6	0.2	0.75	3.5
22	9	0.3	0.5	2
23	6	0.3	0.75	3.5
24	9	0.3	1	5
25	6	0.2	0.75	3.5
26	6	0.2	0.75	2
27	3	0.3	0.5	5
28	3	0.1	1	5
29	6	0.2	0.5	3.5
30	6	0.2	0.75	3.5

accuracy was determined using a significant prototype, non-significant lack-of-fit test, and high R^2 (coefficient of determination). Numerical optimization of the independent variables was carried out to minimize foam density and drainage volume while maximizing expansion volume. In order to validate the reliability of the results, three sets of experiments were replicated for each response. The validation of the optimized conditions involved a comparison between the experimental and predicted outcomes. This was facilitated by the Paired-t test, which gauged the level of concordance between the two sets of results.

The foamed products were dried using a completely randomized design with a single factor distributed across three levels, specifically 50, 60, and 70 °C. Each experimental setup was replicated three times to ensure robustness. Additionally, each response variable was subjected to duplicate analysis. The Excel software was used in conjunction with ANOVA performed using SPSS 13 for data analysis. In instances where treatments showed significant effects, indicated by a p-value of <0.05, the subsequent step involved conducting the Duncan test for a detailed assessment and comparison.

Sample Analysis

The evaluation of the foamed product involved the assessment of specific parameters, namely foam density, expansion, and drainage volumes (Balasubramanian et al., 2012). Additionally, the dried pasta sauce was comprehensively analyzed for various attributes such as moisture content, water activity (), color, water absorption, solubility indexes, and hygroscopicity.

Foam density was determined by carefully pouring about 100 mL sample into a 100 mL measuring cylinder to obtain its volume and weight. Furthermore, the foam density was calculated as the ratio of the sample weight to its volume. Expansion volume was determined by computing the difference between the volume of the foamed sample and its initial volume and subsequently dividing the result by the initial volume of the sample. The drainage volume was determined by positioning the foamed sample in a Buchner filter (with an 80 mm funnel diameter) placed in a 100 mL measuring cylinder. After a 10-minute interval, the liquid collected in the measuring cylinder was recorded and designated as the drainage volume (Balasubramanian et al., 2012).

Moisture content was analyzed following the procedure outlined in SNI 01-2891-1992 for food and beverage testing (BSN, 1992). Furthermore, was determined using a smart water activity meter (model no. HD-3A, China). Color analysis was performed using a colorimeter (NH3, China) based on the CIELab scale. In this scale, the L, A, and B values represent lightness, red-green, and yellow-blue colors, respectively. Water solubility (WSI) and water absorption indexes (WAI) were determined following the procedures outlined by Azizpour et al. (2014) and Shaari et al. (2018) with slight modifications. The values of WSI and WAI were calculated using Equations 2 and 3. Roughly 1 g of the sample was placed in a 50 mL centrifuge tube, and 40 mL distilled water was added. After 10 minutes of vortexing, the mixture underwent centrifugation (Thermo Scientific™ SL 40R Centrifuge Series, Thermo Fisher Scientific Robert-Bosch-Straße 1 D - 63505 Langenselbold, Germany) at 4000 xg for 20 minutes. This led to the careful separation of the supernatant and sediment. The supernatant was collected in a weighing bottle and dried in an oven at 105 °C until a constant weight was reached. The weight of the remaining sediment in the centrifuge tube was also measured. Hygroscopicity was determined by placing approximately 2 g of the sample in a container with a solution of saturated Na_2SO_4 (RH 81%) for seven days (Shaari et al., 2018; Jaya & Das, 2004). The hygroscopicity values were calculated using Equation 4.

$$WSI = \frac{W_O}{W_{sk}} \quad (2)$$

$$WAI = \frac{W_E}{W_S - W_O} \quad (3)$$

$$Hygroscopity = \frac{(\Delta W/W_S) + m_a}{1 + \Delta W/W_S} \quad (4)$$

WO is the constant weight of the supernatant, WE is the weight of the sediment sample, Ws is the weight of the sample, Wsk is the weight of the dry sample, ΔW is the weight increase of the sample, ma is the initial free moisture content of the sample.

RESULTS AND DISCUSSION

Accuracy of Polynomial Regression Model

The average of three replications for each response in every experimental combination was formulated in the general quadratic polynomial model (Equation 4). The estimates of regression and correlation coefficients for each model are shown in Table 3.

The positive and negative signs on the coefficient indicate a synergistic, and diminishing effect, respectively. The responses of foam density and expansion exhibit quadratic equation models. The factors significantly influencing ($p<0.05$) both of these responses are the linear egg white concentration (A), whipping time (C), and water-to-sauce ratio (D). The response of drainage volume yielded a linear predictive model, with the significant factors including the linear egg white concentration (A) and whipping time (C). Quadratic models have also been reported in related research on the foaming of tomato juice. In that context, foam density, expansion, and drainage volume responses were linked to egg white and CMC concentrations, including whipping time (Balasubramanian et al., 2012).

Statistical analysis parameters were used to determine the suitability of the model. These included the p-value of the model, coefficient of determination (R^2), adjusted coefficient (R^2 -adj), predicted coefficient (R^2-pred), the p-value of lack of fit, and adequate precision obtained from the analysis of variance

Table 3. Coefficients of the polynomial regression model for each response

Coefficients	Foam density	Expansion volume	Drainage volume
Model	Quadratic	Quadratic	Linear
β_{k0}	1.099	-0.465	-162.027
β_1	-0.052*	0.121*	-14.410*
β_2	0.416	-0.416	-156.406
β_3	-0.283*	0.538*	694.433*
β_4	-0.040*	0.087*	-13.080
β_{12}	-1.25E-03	-0.051	
β_{13}	-1.74E-04	-3.42E-03	
β_{14}	1.47E-04	2.08E-03	
β_{23}	-0.227	-0.038	
β_{24}	0.040	-0.068	
β_{34}	0.023	0.030	
β_1^2	2.91E-03*	-7.23E-03*	
β_2^2	-0.844	2.074	
β_3^2	0.067	-0.088	
β_4^2	-4.12E-04	4.32E-03	

Description: Symbol * is significant at the 5% level

(ANOVA). The statistical significance of model parameters is determined at a 5% significance level (p-value < 0.05). A comprehensive presentation of the analysis of variance outcomes for the response models is shown in Table 4.

Based on Table 4, the p-values for all responses are less than 0.0001, indicating a high significance level for each model. This robust statistical support allows the proposed models to be confidently employed for optimization. The lack of fit values for all responses, spanning from approximately 0.21 to 0.44, is not significant, as they exceed the 0.05 threshold. This indicates that all generated response models are suitable since there is no lack of fit or deviation. The adjusted R^2 value for foam density is 0.9169, suggesting that the treatment factors influence 91.69% of the data and quadratic model, while the remaining 8.31% is affected by other variables. The difference between the adjusted and predicted R^2 values for all responses is less than 20%, indicating good model performance. The model accuracy is also supported by adequate precision values greater than 4 for all responses (ranging between 14.63 and 24.24).

Foam Expansion

Foam expansion represents the degree of increase in the volume of pasta sauce due to the incorporation of air during foaming. Figure 2 shows the three-dimensional graph of foam expansion, depicting the interplay between egg white and CMC concentrations. It examines scenarios involving a whipping time and water-to-sauce ratio of 3.5 minutes and 0.75, respectively (Figure 2A). Figure 2B shows the influence of whipping time and water-to-sauce ratio when egg white and CMC concentrations are mixed at 0.6% and 0.2%.

Based on Figure 2, an increase in egg white concentration, water-to-sauce ratio, and whipping time leads to an expansion of the foam. However, an increase in CMC concentration results in a decreasing trend in foam expansion. This consistent trend is reinforced by the findings shown in Table 3. The positive linear coefficients tied to egg white concentration, water-to-sauce ratio, and whipping time align with the rise in foam expansion. The negative coefficient associated with CMC concentration supports the observed reduction in foam expansion. This trend similarity was reported in the research on the foaming of pure tomatoes (Balasubramanian et al., 2012). The increase in foam expansion is attributed to the proteinous nature of egg whites. During whipping, protein denaturation occurs in the interphase, fostering the formation of a stable viscoelastic interfacial layer as the nutrients interact with one another. This interaction results in the formation and an increase in the volume of the tomato foam. The decrease in foam expansion with increasing CMC concentration is possibly due to its role

Table 4. Parameter estimates and analysis of variance for response models

Response	*p-value model*	*p-value lack of fit*	*R^2*	*Adjusted R^2*	*Predicted R^2*	*Adequate precision*
Foam density	< 0.0001	0.2086	0.9579	0.9169	0.8198	20.241
Expansion volume	< 0.0001	0.2192	0.9105	0.8269	0.6947	14.632
Drainage volume	< 0.0001	0.4376	0.9005	0.8846	0.8535	24.241

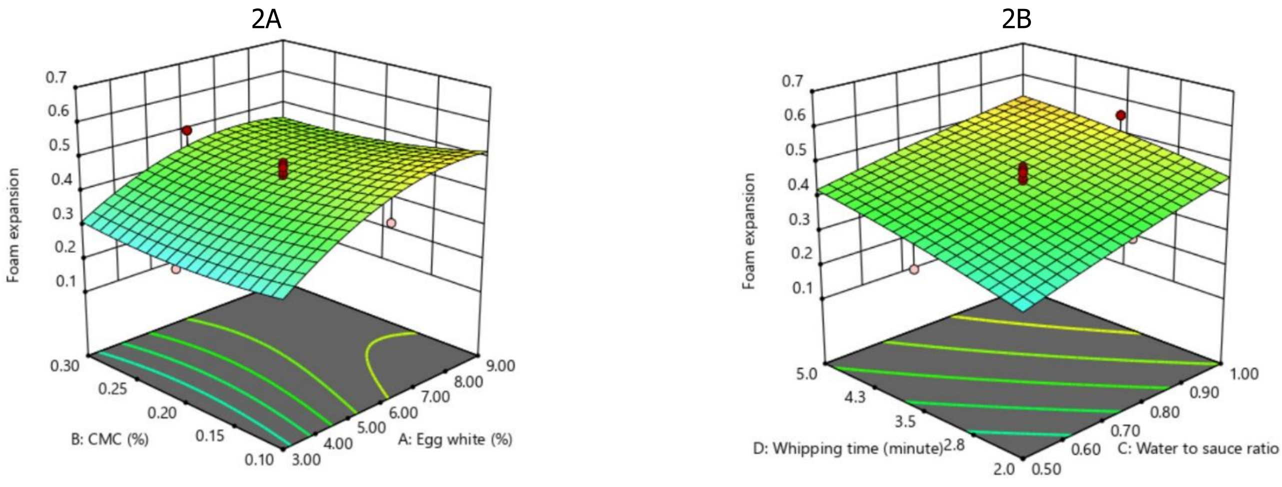

Figure 2. *3D-surface foam expansion*

in stabilizing the foam through heightened viscosity. The stabilization effect becomes counterproductive at higher concentrations, leading to an excessively viscous solution that prevents air from being trapped during whipping (Balasubramanian et al., 2012). This is further supported by an increase in foam expansion and water-to-sauce ratio, leading to a more diluted liquid. An increase in whipping time would lead to greater air entrapment, leading to higher foam expansion (Azizpour et al., 2014).

Foam Density

Foam density is a significant parameter for evaluating the characteristics of the foaming process. It quantifies how air becomes entrapped within the liquid as bubbles during the whipping process. In order to visually illustrate this phenomenon, Figure 3 shows a three-dimensional graph of foam density as influenced by egg white and CMC concentrations. This graphical representation explores two distinct scenarios, one involving a whipping time and water-to-sauce ratio of 3.5 minutes and 0.75 (Figure 3A), and the other investigating the impact of these variables while keeping egg white and CMC concentrations constant at 0.6% and 0.2%, respectively (Figure 3B).

The foam expansion and density of pasta sauce are closely interlinked. An increase in foam expansion tends to potentially result in a decrease in density. This relationship is shown in Figure 3A, where an increase in egg white concentration leads to a decrease in foam density. This finding is supported by the negative value of the linear coefficient in the response model (Table 3). Furthermore, this phenomenon can be rationalized by considering the impact of egg white concentration. An increase in egg white concentration reduces surface tension due to the movement of foaming agents (proteins in egg white) from the liquid phase to the

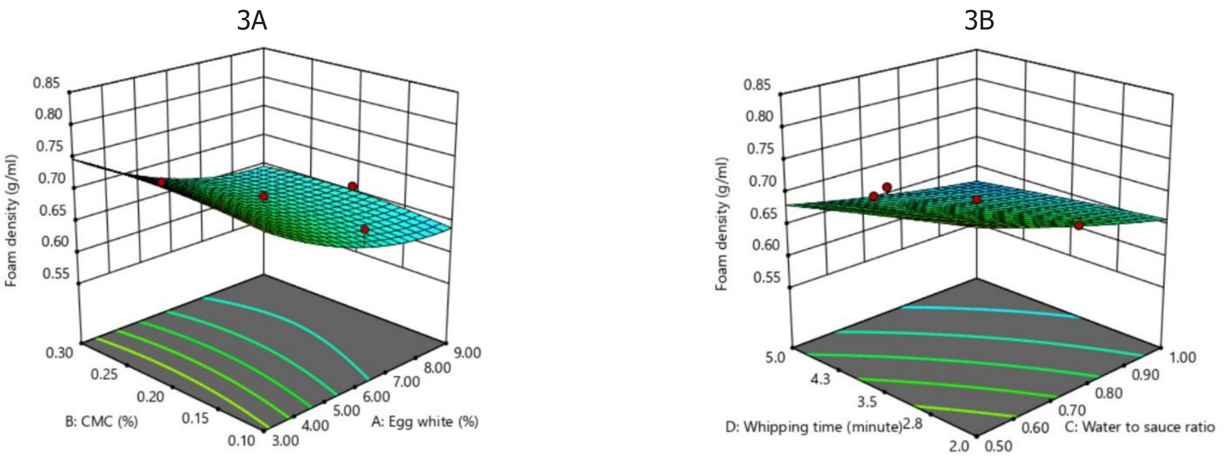

Figure 3. *3D-surface foam density*

air-liquid interface. This dynamic mechanism enhances the ability of the sauce to foam, ultimately leading to a decrease in density (Abbasi & Azizpour, 2016). These findings are consistent with Balasubramanian et al. (2012) and Falade et al. (2003).

Foam density exhibits a synergistic correlation with an increase in CMC concentration, as indicated by the positive value of the linear coefficient in the response model (Table 3). CMC serves as a stabilizing agent during the foaming process. A similar trend was reported in the foaming of shrimp (Azizpour et al., 2014) and soursop fruit pulp (Bag et al., 2011). An increase in the concentration of stabilizing agents resulted in heightened viscosity of the mixture, which hampered the efficient trapped air and increase in foam density (Azizpour et al., 2016). However, foam density decreases with an increase in the water-to-sauce ratio. A similar trend is observed with a longer whipping time, as shown in Figure 3B. These trends align with the negative linear coefficient in the model equation and are consistent with the findings reported by Balasubramanian et al. (2012) and Azizpour et al. (2016). Prolonged whipping time and water-to-sauce ratio (mitigates sauce viscosity) lead to increased air retention in the foam. This, process led to higher and lower foam expansion and density, respectively (Azizpour et al., 2016).

Drainage Volume

Drainage is the flow of liquid through foam driven by either capillary or external forces such as gravity (Salahi et al., 2015). The measurement of drainage volume is an effective way to assess foam stability, providing insights into the amount of liquid expelled from the structure. In order to visually illustrate this concept, Figure 4 shows a three-dimensional graph of drainage volume. The graph captures the correlation between drainage volume and varying egg white and CMC concentrations under specific conditions, namely a whipping time and water-to-sauce ratio of 3.5 minutes and 0.75 (Figure 4A). Figure 4B shows the intricate interplay of whipping time and water-to-sauce ratio while maintaining consistent egg white and CMC concentrations of 0.6% and 0.2%, respectively.

Drainage tends to occur due to the thinning of the lamella, thereby causing the liquid phase to separate from the interfacial layer, potentially leading to film collapse. Bag et al. (2011) stated that drainage volume was influenced by factors such as interfacial thickness and permeability, foam size distribution, and surface tension. The results of pasta sauce foaming (Figure 4) indicate that increasing egg white concentration, water-to-sauce ratio, and whipping time decreased drainage volume. Meanwhile, an increase in CMC concentration tends to trigger drainage volume. A similar trend was reported in the foaming of soursop fruit (Bag et al., 2011), pure tomato (Balasubramanian et al., 2012), wax gourd pulp (Salahi et al., 2015), and shrimp (Azizpour et al., 2016). Higher CMC concentrations result in more stable foam due to increased viscosity. This increase in viscosity serves dual purposes, it shields the delicate film encasing the bubbles (lamella) from collapsing and creates a sticky layer that bolsters foam stability (Bag et al., 2011). An elevated water-to-sauce ratio led to a decline in sauce viscosity, causing more liquid to flow from the foam structure. Salahi et al. (2015) stated that increased foaming agents (egg white) triggered viscosity and interfacial tension of the continuous phase. This phenomenon coincides with an augmentation in film thickness and strength at the air-water interface. Prolonged whipping time leads to more denaturation of egg white proteins, forming stable foam.

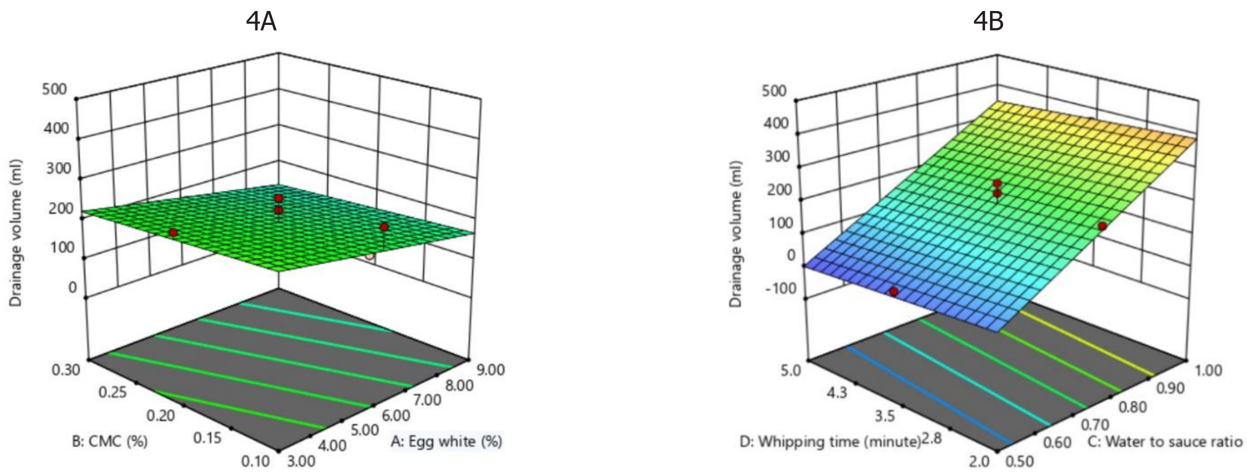

Figure 4. *3D-surface drainage volume*

Table 5. Validity results in optimal conditions

Response	Predicted value	Experiment value	P-value *(paired t-test)*
Foam density, g/mL	0.6298	0.6045	0.238
Expansion volume	0.5284	0.5376	0.677
Drainage volume, mL	5.0019	5.2778	0.892

Table 6. Characteristics of pasta sauce powder

Treatment	Moisture (%)	a_w	WAI (g/g)	WSI (%)	Hygroscopicity (%)
T50	8.78 ± 0.24[c]	0.23 ± 0.01[b]	8.62 ± 0.81[a]	0.51 ± 0.06[a]	6.54 ± 0.13[c]
T60	7.67 ± 0.08[b]	0.21 ± 0.01[a]	8.55 ± 0.37[a]	0.53 ± 0.06[a]	5.65 ± 0.05[b]
T70	6.51 ± 0.27[a]	0.19 ± 0.01[a]	8.23 ± 0.82[a]	0.61 ± 0.06[b]	4.65 ± 0.17[a]

Description: Different letters in the same column indicate a significant difference (p>0.05)

Process Optimization

The desirability function was applied to select the optimum conditions for pasta sauce foaming. Afifah et al. (2022) reported that a decrease and an increase in density and foam expansion contributed to the effective diffusivity during foam drying. This accelerated drying process maintains product quality by limiting its exposure to hot air. Therefore, the desirability function aimed to minimize foam density and drainage volume with rise in its expansion. All response variables were assigned an equal importance level of 3 on the scale. The optimum conditions were achieved with egg white and CMC concentrations of 8.99% and 0.1%, alongside a water-to-sauce ratio and whipping time of 0.54:1 and 5 minutes. This specific combination yielded a desirability value of 0.87%. The optimum value of foam density, drainage volume, and expansion volume from the process optimization was 0.63 g/mL; 5 mL; and 0.53, respectively. In order to validate the predicted results, three sets of experiments were conducted for each response under these ideal conditions. The validation tests conducted under these optimal conditions are concisely shown in Table 5. Based on the table, the p-values for all responses are significant ($p > 0.05$). This implies no significant difference between the predicted and experimental results.

Moisture Content and Water Activity of Pasta sauce Powder

The pasta sauce powder displays varying moisture content and water activity levels, ranging from 6.51% to 8.78% and 0.19 to 0.23, respectively (Table 6). Based on the analysis, higher drying temperatures lead to lower moisture content and activity in the pasta sauce powder. A similar trend was also reported by the research on the drying of cherry and tomato plum (Obadina et al., 2018), shrimp (Azizpour et al., 2016), and chili powders (Poonnakasem, 2021), as well as roselle extract (Djaeni et al., 2018). The reduction in water activity is attributed to the loss of water content during the drying process. High-temperature drying can cause the structure of the material to be more porous, thereby hastening the reduction in moisture content. Thuwapanichayanan et al. (2008) stated that increased temperature effectively enhanced the diffusion of moisture content. Moreover, drying can cause denaturation, resulting in the unfolding of proteins, with decrease in their capacity to retain water, thereby affecting the low water activity value of the product (Azizpour et al., 2016).

The moisture content and activity values of the pasta sauce powder obtained in this research are similar to the findings of Poonnakasem (2021). The investigation carried out by Poonnakasem focused on Chili sauce powder dried at temperatures of 60, 70, and 80 °C, showing moisture contents and activities ranging from 3.48% to 7.89% and 0.15 to 0.27. The pasta sauce powder in the present research has a lower moisture content than the maximum requirement specified in the Indonesian National Standard (SNI) 01-3709-1995 for powdered spice products, which is 12% (BSN, 1995). Generally, dry food products maintain a water activity value of approximately 0.2, a level known for ensuring microbiological safety during storage (Wang & Brennan, 1991). Moisture content and activity significantly impact food products in terms of storage, microbial stability, non-enzymatic browning reactions, lipid oxidation, and enzymatic reactions during storage (Prachayawarakorn et al., 2008).

Water Absorption Index (WAI)

The analysis of the pasta sauce powder dried at temperatures of 50 to 70 °C yielded WAI scores ranging from 8.23 to 8.62 (g/g), as shown in Table 6. WAI showed no significant differences, although a decreasing trend was recorded with an increase in drying temperature, consistent with the reduced moisture content in the material. This reduction in WAI could be attributed to the decreased moisture content in the pasta sauce powder dried at higher temperatures, which limits the capacity of the material to absorb moisture. Higher moisture content triggers absorption as liquid easily penetrates the pores, enhancing moisture dispersion (Franco et al., 2016). The decreased water absorption index capacity due to increased drying temperature was also found in foam-mat dried muskmelon powder (Asokapandian et al., 2016). WAI capacity is influenced by factors such as foaming agent concentration (egg white) and duration, protein denaturation, starch gelatinization, and the swelling of coarse fibers during processing into flour (Wilson et al., 2014). Free hydroxyl groups in foaming agents facilitate the binding of water molecules from the surrounding environment, thereby affecting the water absorption index of dry food materials (powders) (Munawar et al., 2020).

Water Solubility Index (WSI)

Based on Table 6, the dried pasta sauce powder analysis showcased a notable increase in the WSI score as the drying temperature advanced. There was no significant difference in WSI capacity between powdered pasta sauce dried at 50 and 60 °C. However, a significant difference was observed in powdered pasta sauce dried at 70 °C, with the highest WSI score of 0.61%. The trend of WSI enhancement with temperature is consistent with preliminary research findings on foam-mat dried bananas (Watharkar et al., 2021) and sour cherry powder products (Abbasi & Azizpour, 2016). A powder exhibiting favorable solubility absorbs moisture, settles, and evenly spreads without undue swelling on the surface. Generally, the food structure becomes more porous at higher temperatures, accelerating water content reduction. Lower water content increases the surface area for water binding, improving powder solubility (Watharkar et al., 2021). Foaming agents are instrumental in producing foams with heightened expansion, facilitating enhanced powder permeability and increasing solubility. The more foam produced during the drying process, the lower the water content of the resulting powder, which turns out to be less sticky, thereby increasing the available surface area (Shaari et al., 2018).

Hygroscopicity

Hygroscopicity is the ability of dry powdered food materials to absorb water vapor from the environment when the relative humidity exceeds the equilibrium moisture content. This property is typically divided into five categories, namely materials with hygroscopicity levels <10% are classified as non-hygroscopic, those between 10.1 to 15% as slightly hygroscopic, 15.1 to 20% as hygroscopic, 20.1 to 25% as highly hygroscopic, and >25% as very highly hygroscopic (GEA Niro Research Laboratory, 2005). The analysis of the dried pasta sauce powder in Table 6 shows that the hygroscopicity score decreases as the drying temperature increases. This phenomenon is attributed to temperature-induced changes that alter the mobility of water molecules, resulting in a thermodynamic equilibrium between the vapor and adsorbed phases (Araújo & Pena, 2020). Similarly, Ouaabou et al. (2021) stated that higher drying temperatures reduces the equilibrium moisture content of cherry powder. As the temperature increases, water molecules gain energy, thereby weakening the attractive forces and causing a decrease in the equilibrium moisture content, leading to lower hygroscopicity. The hygroscopicity values observed in the dried samples range from 4.65% to 6.54%, categorizing the products as non-hygroscopic materials. Hygroscopicity is related to the physical, chemical, and microbiological stability of products. The polar conformation in egg-white structures enhances the ability of the powder to attract water vapor molecules when in contact with the surrounding air (Shaari et al., 2018).

Color of Pasta sauce Powder

Color is one of the most important attributes of dry and powdered products, significantly influencing their price and consumer interest. The color analysis shows that the redness index (a value) of the pasta sauce powder decreases with increasing drying temperature, although not significantly. However, both the lightness (L value) and the yellowness indexes (c value) exhibit a significant increase as the drying temperature rises (Table 7). These results are consistent with the research conducted by Obadina et al. (2018) on cherry tomato powder. In the research, a decrease in red color pigmentation corresponded with a rise in the L value, indicating heightened product brightness. The decrease in the redness index of the pasta sauce is attributed to the breakdown of lycopene, the primary contributor to the red carotenoid pigment found in tomatoes. Albano et al. (2011) reported that the decrease in the redness index of tomato powder is due to the Maillard reaction between amino acids and reducing sugars during drying.

Table 7. Color characteristics of pasta sauce powder

Treatment	L	A	B
T50	56.32 ± 1.39[a]	13.81 ± 0.12[a]	15.49 ± 0.64[a]
T60	57.21 ± 1.01[a]	13.83 ± 0.55[a]	16.01 ± 0.55[a]
T70	58.57 ± 0.57[b]	13.57 ± 0.27[a]	17.08 ± 0.20[b]

Description: Different letters in the same column indicate a significant difference (p>0.05)

The pasta sauce powder dried at 70°C has the highest L and b values, specifically 58.57 and 17.08, respectively. This indicates that the sample is the brightest color and displayed a more pronounced yellow hue than those dried at 50 and 60 °C. The increase in temperature, resulting from higher microwave wavelengths during the foaming drying process, triggered the coagulation of egg white. This outcome produces tomato pulp powder with enhanced brightness (L value) (Qadri & Srivastava, 2014). Albano et al. (2011) stated that the increase in the b value in tomato slices with rise in drying temperature, reduced the browning effect in the product.

The optimal drying temperature is determined by considering the physicochemical characteristics of the product. Based on Tables 5 and 6, the moisture content values of all temperature treatments met the requirements of SNI 01-3709-1995 and fell within the category of non-hygroscopic products. The initial moisture content (a_w) of the dried pasta sauce at 60 °C is approximately 0.2 and not significantly different from the 70 °C treatment. However, in terms of color, there is a significant difference, with the 60 °C treatment exhibiting better color retention. The optimal drying temperature is established as 60 °C.

CONCLUSION

In conclusion, the foaming of the pasta sauce showed that an increase in egg white concentration, water ratio, and whipping time resulted in expanded foam, decreased foam density, and reduced drainage volume. Meanwhile, increased CMC concentration reduced foam expansion and elevated its density as well we drainage volume. The optimal conditions to achieve the best foam properties were 8.99% egg white concentration, 0.1% CMC concentration, a water ratio to paste of 0.54:1, and 5 minutes of whipping time. Elevated drying temperatures led to decreased moisture content, WAI (Water Absorption Index), and hygroscopicity of the dried pasta sauce. Meanwhile, WSI (Water Solubility Index) and color (brightness) exhibited an inclination to increase. The optimal drying temperature to produce the finest pasta sauce powder was established at 60 °C. It was characterized by the following attributes, namely 7.67% moisture content, 0.21 a_w (water activity), 8.55 g/g WAI, 0.53% WSI, 5.65% hygroscopicity and color (L: 57.21, a: 13.83, b: 16.01).

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CONFLICT OF INTEREST

The authors declare no conflict of interest from any other party.

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