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Optimization of Drum Drying Parameters for Chicken Egg White Flour Using Response Surface Methodology

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ABSTRACT

Chicken egg white flour production is crucial due to the growing demand for high-quality protein sources. Drum drying, known for its rapid drying capabilities, can influence the physicochemical properties of egg flour. However, existing literature lacks studies that evaluate the impact of various drum drying conditions on the characteristics of egg white flour. This research employs Response Surface Methodology (RSM) to identify optimal drying parameters to maximize yield and preserve the functional integrity of egg white flour. Independent factors include steam pressure in the range of 2.5-3.5 bar and drum rotation speed in the range of 1-2 rpm. The results of RSM show that optimal conditions are obtained with a desirability value of 0.542. Process parameters of 3.5 bar steam pressure and 2 rpm drum rotation yielded this optimal characteristic. This process effectively optimizes the physicochemical properties of chicken egg white powder resulting in a specific water content (5.50%), ash (2.23%), protein (50.28%), fat (0.17%), carbohydrates (41.81%), water activity (0.34), and yield (25.33%). The findings suggest that selected drying conditions can lead to improved yield and maintain its quality (especially protein content), thereby enhancing the overall utility of chicken egg white flour in various culinary and industrial applications.

1. INTRODUCTION

Protein fulfillment is of paramount importance for the human body. Animal protein sources can be attained through the consumption of meat and eggs. Eggs are considered to be of great importance for human health due to their rich composition of crucial nutrients [1-3]. They are a fundamental dietary component due to their affordability and widespread availability. Consequently, eggs have gained significant popularity among individuals, resulting in a substantial consumption of chicken eggs within the community and their frequent incorporation in food processing applications, such as bread and pastries [4]. According to the data provided by the Indonesian Central Statistics Agency [5], egg production in Indonesia reached a significant volume of 5,566,339 metric tons in 2022. The consumption of chicken eggs in Indonesia has witnessed a notable surge following the onset of the epidemic. In the year 2021, there was a significant upward trend observed in the average per capita weekly egg intake, reaching a value of 2,448 kg.

Despite being classified as perishable food products [6], eggs continue to play a major role in the diet of the Indonesian population. The Republic of Indonesia continues to engage in the importation of egg powder due to its constrained domestic egg production capabilities. Indonesia has a substantial populace characterized by a pronounced need for eggs and egg-based commodities; domestic egg production needs to do more to satisfy this demand adequately. Consequently, Indonesia depends on imports to fulfill the need for egg powder.

In January 2023, the Central Statistics Agency of the Republic of Indonesia documented a rise in the importation of egg powder compared to the corresponding period in January 2022. In January 2023, the quantity of poultry eggs imported amounted to 165,690 kg, which exhibited a notable surge of 118.46% compared to the previous high of 75,840 kilograms observed in January 2022. India is Indonesia's primary source of imported poultry egg powder, accounting for a total of 165,670 kg; this is a significant increase of 120.61% compared to the corresponding period in January 2022. The provided data analysis reveals a notable rise in egg consumption and importation. This trend underscores the imperative for implementing effective egg processing and preservation techniques, prolonging their shelf life for a particular duration.

Drying is a preservation technique that entails the extraction of moisture from food items. One method of egg processing is the conversion of fresh eggs into powdered form. Egg powder, alternatively referred to as dried eggs, is a variety of eggs that undergo preservation by a series of procedures involving drying and milling. Egg powder has several advantages, including an increased shelf life and reduced size, enhanced storage efficiency and decreased transportation expenses.

The process of egg drying can be accomplished by a range of techniques, including using a drum dryer. A drum dryer has a drum-shaped structure that undergoes continuous rotation and is subjected to heat from a furnace or gasifier [7]. Andriani et al. [8] discovered a positive correlation between drying temperature and the water absorption capacity (WAC) of the powder. Rodiahwati [9] and Ardiansyah et al. [10] posited that, in addition to temperature, a drum dryer's rotational speed (RPM) is a significant element influencing both the drying rate and the ultimate moisture content of materials subjected to the drying process. However, research on egg flour production using drum dryers is limited. Throughout the literature, only three articles were found that used a drum dyer to produce egg flour, and that too only for egg yolk [11-13], and not for egg white. In addition, optimizing the drying conditions to produce egg white flour is crucial, because the aim is to produce a high yield while maintaining the content to meet the criteria. Thus, the RSM is the selected method for optimization. RSM is employed to optimize operations by examining the impact of various reaction circumstances on achieving an ideal outcome.

Based on the above explanation, the purpose of this study is to determine the optimal drum drying process parameters for chicken egg white powder production using response surface methodology with high yield and protein criteria and low moisture content.

2. MATERIALS AND METHODS

2.1 Raw materials

The constituents employed in the production process of egg white powder encompassing chicken eggs and maltodextrin. Some of the chemicals used for analysis are samples, distilled water, 25% hydrochloric acid (HCl), nitrogen gas, n-hexane, sodium chloride (NaCl), buffer solutions with pH values between 4 and 7, and 95% ethanol. Characteristics of chicken egg white before and after maltodextrin addition is shown in Table 1. Based on this information, the sample formula used for optimization was chicken egg white + maltodextrin.

Table 1. Characteristics of raw materials used for experiment

Sample	Chicken Egg White	Chicken Egg White + Maltodextrin
Moisture (%)	84.36±0.03	84.37±0.03
Ash (%)	0.64±0.03	0.64±.0.00
Fat (%)	0.11±0.02	0.09±0.01
Protein (%)	10.82±0.00	10.63±0.00
Carbohydrate (%)	4.07±0.04	4.27±0.05
pH	7.69±0.03	7.60±0.03

2.2 Experimental conditions

The present study investigated raw materials, specifically commercial chicken eggs, to assess their nutritional quality before undergoing the drying process. The objective was to compare the nutritional values before and after conversion into powder. The process conditions were determined using *Design Expert Trial version 13* (Stat-Ease, Inc., USA), with fixed variables consisting of 83% egg white and 17% maltodextrin. The manipulated variable in question pertained to the alteration of the drum dryer process, namely the adjustment of the steam pressure within the range of 2.5-3.5 bar and the modification of the drum rotation speed within the range of 1-2 rpm. The *Design Expert* program processed the data, resulting in 10 formula conditions as shown in Table 2.

Table 2. Design of experiment generated by *Design Expert*

Run	Steam Pressure (bar)	Drum Rotation (rpm)
1	3.0	1.5
2	3.5	1.0
3	2.5	1.0
4	2.3	1.5
5	3.0	0.8
6	3.0	2.2
7	3.7	1.5
8	3.5	2.0
9	2.5	2.0
10	3.0	1.5

The heat source used to run the drying drum was an electrical heater steamer. The steamer can be regulated in a pressure range between 2 and 3.8 bar. Pressure affected the temperature of the drum as can be seen in Figure 1. When the pressure reaches the set-point pressure, the electricity automatically turns off, and vice versa. There are four stages in operating a drum dryer: 1) turning on the steamer and waiting until the pressure reaches the set point; 2) opening the valve that connects the steamer to the drum; and 3) setting the drum speed rotation, 4) waiting until the pressure reaches the target, and the drying drum is ready for use. Pressure monitoring was carried out with a pressure gauge with an accuracy of 0.1 bar. The drum surface temperature was measured using a type K thermocouple with an accuracy of 0.1°C. Drum rotation was measured using a tachometer with an accuracy of 1 rpm.

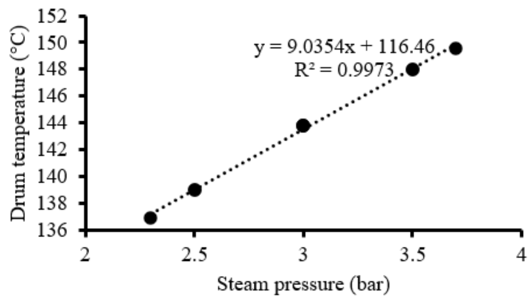

Figure 1. Linear relationship between steam pressure and drum temperature

The utilized measurements encompassed moisture and ash content was determined using the gravimetric method [14]. Protein analysis using the combustion method was carried out using a Buchi® DuMaster D-480 instrument [15]. Fat content was determined by the Soxhlet method [10]. Carbohydrate content was analyzed by the Luff Schoorl method [16]. Water activity, yield, color was measured according to Tarlak et al. [17]. Solubility time, wettability, hygroscopicity, bulk density [18]. tapped density, cohesiveness, flowability, and WAC was determined according to Onyango et al. [19].

2.3 Statistical analysis and optimization using RSM

After conducting experiments based on the generated experimental design, response data were input into *Design Expert trial version 13* (Stat-Ease, Inc., USA) program with the Response Surface Methodology - Central Composite Design approach. Design Expert then automatically performed model fitting based on a polynomial approach. The adequacy of the model was assessed using statistical criteria such as R^2, "Adjusted R^2", and lack-of-fit. Design Expert focuses on maximizing the "Adjusted R^2" and the "Predicted R^2", and selecting a model with insignificant lack-of-fit. Design Expert performs analysis of variance (ANOVA) to determine the significance of the factors and interactions in the model. This helps in understanding which variables have a significant effect on the response. Optimization was performed by exploring the response surface, then several criteria were set to obtain an optimized model. Set goals for numerical optimization and their importance level is shown in Table 3. After optimization, validation was carried out by conducting confirmatory experiments at the predicted optimal conditions.

Table 3. Numerical optimization parameters

Name	Goal	Importance Level
Pressure	is in range	5
Rotation	is in range	5
Yield	maximize	5
Protein	maximize	5
L*	maximize	5
a*	minimize	5
b*	minimize	5
Solubility time	minimize	5
Wettability	minimize	5
Moisture	minimize	5
Ash	minimize	5
Fat	minimize	5
Carbohydrate	minimize	5
aw	minimize	5
Hygroscopicity	minimize	5
Bulk density	minimize	5
Tapped density	minimize	5
Flowability	minimize	5
Cohesiveness	minimize	5
WAC	minimize	5

Table 4. Responses physical and chemical properties of chicken egg white flour using drum dryer

Response	Run									
	1	2	3	4	5	6	7	8	9	10
Moisture Content (%)	5.38	4.87	4.48	6.29	3.23	6.00	5.19	5.48	6.97	4.06
Ash Content (%)	2.51	2.73	2.64	2.53	3.76	2.51	2.49	2.52	2.50	2.63
Protein Content (%)	35.34	36.60	36.39	35.43	54.41	36.22	35.83	35.45	33.62	37.18
Fat Content (%)	0.17	0.12	0.15	0.13	0.09	0.12	0.33	0.41	0.42	0.33
Carbohydrate Content (%)	56.60	55.68	56.33	55.61	38.50	55.15	56.17	56.14	56.49	55.80
Water Activity (a_w)	0.42	0.37	0.39	0.47	0.30	0.43	0.31	0.35	0.42	0.36
Yield (%)	25.33	24.33	25.33	25.50	16.00	24.50	23.17	24.50	25.17	24.67
Color L*	62.13	61.61	62.30	64.66	61.37	63.69	64.85	63.90	62.71	65.94
Color a*	1.75	2.34	1.97	1.53	2.99	1.04	2.10	1.40	1.19	1.75
Color b*	14.16	14.11	13.53	13.65	16.16	11.61	14.94	12.97	11.90	14.31
Solubility Time (sec)	13.89	14.25	12.09	13.99	12.44	12.52	11.07	12.51	12.91	14.55
Wettability (sec)	25.06	23.41	21.45	18.95	25.15	20.92	24.21	18.60	20.11	23.66
Hygroscopicity (%)	4.81	7.39	6.86	4.58	9.46	4.27	6.35	5.22	3.97	3.58
Bulk Density (g/mL)	0.54	0.51	0.56	0.50	0.50	0.46	0.49	0.45	0.48	0.53
Tapped Density (g/mL)	0.65	0.63	0.67	0.60	0.61	0.55	0.59	0.55	0.58	0.64
Flowabilitty	0.18	0.20	0.16	0.16	0.18	0.16	0.18	0.19	0.16	0.16
Cohesiveness	1.21	1.25	1.19	1.19	1.21	1.20	1.21	1.23	1.19	1.19
WAC (%)	244.55	247.71	239.19	241.32	317.68	268.78	256.48	265.63	263.82	266.80

3. RESULTS AND DISCUSSION

3.1 Chemical responses

The results obtained from the analysis of moisture, ash, protein, fat, carbohydrate, and pH in the raw materials can be seen in Table 4.

Results show that process conditions significantly affect the moisture content of egg white powder. The response surface graph as shown in Figure 2(a) displays process conditions interaction, with blue representing the lowest moisture content of 3.23% (at 3 bar pressure and 0.79 rpm rotation) and red the highest of 6.97% (at 2.5 bar pressure and 2 rpm rotation). Moisture content testing measures water quantity in egg white powder, a critical factor affecting product shelf life. Excessive moisture can alter physical properties and durability. Raw egg white, with a moisture content of 84.36%, was reduced to an optimal 5.50% in the powder form due to the drying process. The final moisture content and color changes depend on the drying process and heat exposure duration. High rotation speeds can lead to insufficient drying [20]. In this study, a trend was found that the water content decreased with increasing pressure and increased with increasing rpm. This is in line with research by Setiyawan et al. [11] who found the same trend in egg yolk flour products. This is because increasing pressure increases the temperature of the drum so that the rate of water evaporation becomes greater. Based on the quality standards for egg white flour in Indonesia, this water content value is in accordance with the SNI 01-4323-1996 standard where the maximum water content value is 8% [21]. Thus, a water content of 5.50% is a very good value because the lower the water content, the smaller the possibility for microbes to grow.

Process conditions didn't significantly affect the ash content of egg white powder. This means that the temperature and rpm in the range used do not have a different impact between all treatments, so any condition can be used. Figure 2(b) shows the lowest ash content of 2.49% (at 3.71 bar pressure and 1.5 rpm rotation) and the highest of 3.76% (at 3 bar pressure and 0.79 rpm rotation). Ash content testing measures potentially toxic minerals in egg white powder, with raw egg white having 0.64% ash and the optimal ash content in the powder being 2.23%. Ash content, representing mineral levels, generally remains stable with storage but can increase with moisture content [22]. The results of this ash value are in accordance with the standard for egg white flour in Indonesia where the maximum content is 5% [21].

Regarding protein content, process conditions didn't significantly affect the protein content of egg white powder. Figure 2(c) displays process conditions interaction, with blue representing the lowest protein content of 33.62% (at 2.5 bar pressure and 2 rpm rotation) and red the highest of 54.41% (at 3 bar pressure and 0.79 rpm rotation). Protein content testing determines protein levels in food ingredients, crucial for amino acids. The raw egg's protein content was 10.82%, and the optimal content in the powder was 50.28%, with the increase attributable to low moisture content leading to higher total solids, including protein. Despite potential denaturation at high temperatures and prolonged drying, significant protein loss is unlikely [23]. Regarding standards related to egg white flour, the National Standardization Agency of the Republic of Indonesia recommends a protein value of around 75% [21]. Thus, the results in this study are still less than these standards. This is due to the excessive use of fillers, viz. maltodextrin which is rich in carbohydrates. Therefore, further research needs to optimize the maltodextrin ratio used so that protein levels according to standards can be achieved. However, in principle, the use of a drum dyer has been able to produce egg flour with appropriate water content criteria, so that protein is only related to the composition of the ingredients used.

It was also found that process conditions didn't significantly affect the fat content of egg white powder. Figure 2(d) shows that the lowest fat content was 0.09% (at 3 bar pressure and 0.79 rpm rotation) and the highest fat content was 0.42% (at 2.5 bar pressure and 2 rpm rotation). Fat content testing measures crude and total fat, essential for human health. Fat yields 9 kcal per gram, more efficient than the 4 kcal from carbohydrates and protein, and is a solvent for vitamins A, D, E, and K [23]. Raw chicken eggs have 0.11% fat, which increases to 0.17% in egg white powder due to the drying process. Higher temperatures and longer drying times lead to increased fat content as heat triggers the decomposition of fat into glycerol and fatty acids [24]. The fat content in egg flour as a result of this research is in accordance with SNI standards, which is below 1% [21].

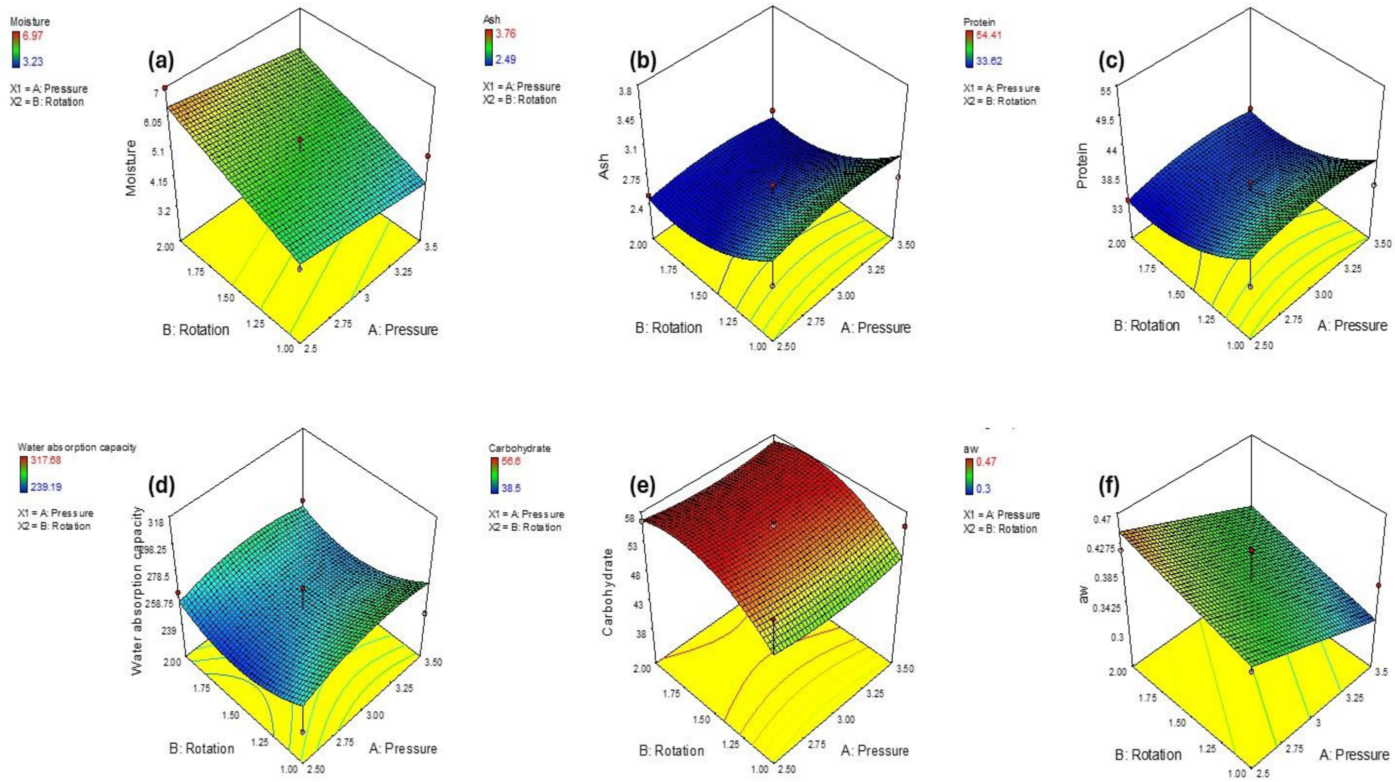

Figure 2. 3D contour plot of chemical response for moisture content (a), ash content (b), protein content (c), fat content (d), carbohydrate content (e), water activity (f)

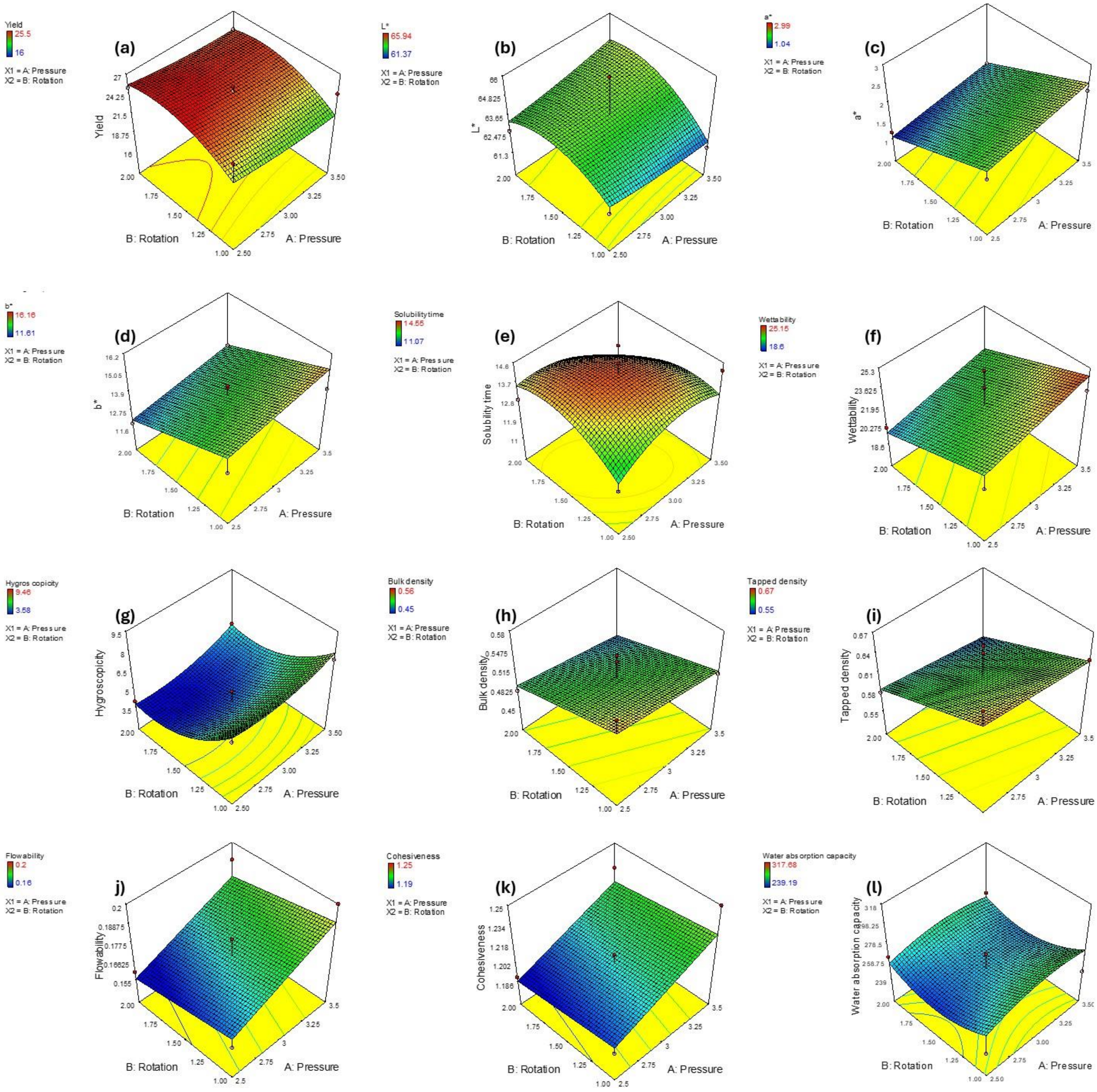

Figure 3. 3D contour plot of physical response for yield (a), L* value (b), a* value (c), b* value (d), dissolution time (e), wettability (f), hygroscopicity (g), bulk density (h), tapped density (i), flowability (j), cohesiveness (k), WAC (l)

Process conditions didn't significantly affect the carbohydrate content of egg white powder. Figure 2(e) displays process conditions interaction, with blue representing the lowest carbohydrate content of 38.50% (at 3 bar pressure and 0.79 rpm rotation) and red the highest of 56.60% (at 3 bar pressure and 1.5 rpm rotation). Carbohydrate content testing measures the amount in egg white powder, with raw eggs having 4.07% and the optimal content in the powder being 41.81%. Carbohydrate content varies inversely with other nutritional components, including water, ash, protein, and fat [20]. Meanwhile, a significant model with a "prob>F" value of 0.0271 and an F value of 6.31 indicates that process conditions significantly affect the water activity in egg white powder. Carbohydrates are an important macro component for the body, but in terms of developing egg white flour, this value is too large because the target of egg flour is to provide protein-rich flour. Thus, as has been explained, it is necessary to reduce the ratio of fillers used, in this case maltodextrin.

Furthermore**,** Figure 2(f) displays a_w parameter, with blue representing the lowest a_w of 0.30 (at 3 bar pressure and 0.79 rpm rotation) and red the highest of 0.47 (at 2.29 bar pressure and 1.5 rpm rotation). Water activity testing, crucial for understanding the chemical and biological aspects of food, is linked with moisture content and affects food shelf life. High water activity reduces shelf life, while low water activity increases resistance against microbial growth. Bacteria thrive at an Aw of 0.9, yeast at 0.8-0.9, and mould at 0.6-0.7.

3.2 Physical responses

Figure 3 shows the surface response of the physical properties data of egg white flour. Yield, a critical facet of the drying process, remained relatively unaffected by the tested process conditions. However, the introduction of maltodextrin seemed to enhance yield due to its carbohydrate content, consistent with prior research findings [23]. The color intensity (L* value) of egg white flour showed no significant alterations under different process conditions. However, notable variations were observed in both the a* and b* values. Higher a* and b* values denote increased redness and yellowness, respectively, potentially valuable in specific applications. A low L* value (<50) indicates a dark color, and a value of 51-100 indicates a light color [25].

Remarkably, dissolution time, a key metric for product usability, exhibited minor fluctuations across the tested conditions, likely influenced by moisture content. Dissolution time testing measures how long a powder needs to dissolve completely in a specific volume, with moisture content affecting the dissolution time. Higher moisture content in the powder product results in a longer dissolution time [26].

Wettability, remained largely unaffected by the process conditions, suggesting consistent performance across various applications. The wettability test evaluates a substance's spread or absorption on a surface, crucial in industries like chemistry, pharmaceuticals, food, and materials.

Hygroscopicity, indicative of moisture absorption, demonstrated significant variability, impacting the flour's stability and moisture regulation properties [27]. The hygroscopicity test measures a material's ability to absorb or release moisture, indicating its durability, stability, and moisture regulation. Low moisture content products have high hygroscopicity due to a higher absorption ability [27] categorizes egg white flour as non-hygroscopic, with a hygroscopicity level ranging from 3.58% to 9.46%.

Flowability and cohesiveness, pivotal for handling and processing, also displayed significant variations, highlighting potential differences in product behavior across diverse conditions. The flowability test measures the flow behavior of powders or granular materials, assessing the material's ability to flow under specific conditions, determining flow properties like flow rate, angle of repose, flowability index, and related parameters.

Lastly, WAC showcased substantial variability, affecting the flour's ability to form dough and overall quality. The WAC test is used to formulate a dough mixture and assess the quality of egg white flour.

3.3 Optimal condition

Optimal process condition was obtained using 3.5 bar steam pressure and 2 rpm drum rotation speed with desirability of 0.542. The desirability value, representing the accuracy of the optimal solution or formulation, is highly influenced by the complexity of the components, their range, the number of components and responses, and the target to be achieved. A desirability value nearing 1 becomes harder to achieve with the increasing complexity of test variables and the optimization target value [28]. Table 5 shows the comparison between experimental and prediction using mathematical model made by RSM. Furthermore, the average pH value of 7.2 from the optimal formula meets the quality standards set by the Indonesian National Standard [29] and the Food and Drug Administration [30], which specify a pH range of 6.5-7.5 for egg white flour.

The response verification results in Table 4 show the data from the chemical response analysis of water content, ash content, protein content, fat content, carbohydrates, physical response to yield, color intensity (a* and b*), dissolution time, bulk density, tapped density, flowability, cohesiveness, and WAC meet the 95% Confidence Interval (CI) prediction. Validation of chemical response analysis of water content, ash content, protein content, fat content, carbohydrates, physical response of yield, color intensity b*, dissolution time, wettability, hygroscopicity, bulk density, tapped density, flowability, cohesiveness, and WAC meet predictions 95% Prediction Interval (PI).

Table 5. Properties of egg white flour processed under optimal condition

Response	Results		95% CI Low	95% CI High	95% PI Low	95% PI High
	Actual	Prediction				
Moisture Content (%)	5.5031	5.7363	4.6984	6.7742	3.6979	7.7747
Ash (%)	2.2332	2.4346	1.7717	3.0976	1.3657	3.5036
Protein (%)	50.282	37.929	17.639	58.219	8.2278	67.63
Fat (%)	0.17	0.3331	0.1673	0.4988	0.0075	0.6586
Carbohydrate (%)	41.807	53.74	34.335	73.144	25.334	82.145
Water Activity (a_w)	0.339	0.3662	0.3153	0.4171	0.2663	0.4661
Yield (%)	25.333	23.229	12.912	33.546	8.1263	38.332
Color L*	88.546	64.447	61.092	67.803	59.036	69.859
Color a*	0.1495	1.4198	1.1457	1.6939	0.8815	1.9581
Color b*	12.259	13.017	11.905	14.13	10.833	15.202
Solubility Time (sec)	12.56	12.293	10.095	14.49	9.0756	15.509
Wettability (sec)	18.01	21.62	18.801	24.438	16.085	27.155
Hygroscopicity (%)	3.4481	5.1741	3.7619	6.5863	2.897	7.4512
Bulk Density (g/mL)	0.47	0.4638	0.4276	0.5	0.3927	0.5349
Tapped Density (g/mL)	0.5697	0.5654	0.524	0.6067	0.4842	0.6466
Flowability	0.175	0.1788	0.166	0.1915	0.1537	0.2038
Cohesiveness	1.2121	1.2188	1.1998	1.2377	1.1816	1.256
WAC (%)	261.99	274.12	192.42	355.81	154.53	393.7

4. CONCLUSIONS

The analysis reveals that process conditions significantly affect the moisture content and water activity of egg white powder, crucial for its shelf life and microbial growth. Macro component such as ash, protein, fat, and carbohydrate contents remain relatively unaffected by these conditions. Physical properties such as yield, color attributes, dissolution time, wettability, hygroscopicity, flowability, cohesion, and WAC exhibit significant variability, highlighting potential differences in product behavior. In general, increased pressure results in a decrease in the water content, whereas an increase in rpm increases the water content. This makes this process very intriguing because an increase in pressure requires more energy; therefore, it needs to be minimized. RPM needs to be maximized to produce high yields, but with a water content that matches the criteria. Optimization using RSM produces an output in the form of optimal operating conditions in which the target characteristics are obtained. The optimal processing conditions obtained was 3.5 bar steam pressure and 2 rpm drum rotation speed, achieving a desirability score of 0.542. The moisture content was 5.50% and yield was 25.33%. This optimization aligns with quality standards, as the average pH of 7.2 falls within the acceptable range set by regulatory bodies.

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