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Effect of Fermentation Time and Spray Drying Inlet Temperature on the Quality of Egg White Powder

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ABSTRACT

Eggs are an affordable and widely consumed protein source but have a limited shelf life due to their perishable nature. Converting egg white into powder through fermentation and spray drying offers a promising preservation method; however, the combined effects of these processes remain insufficiently studied. This research evaluated the influence of fermentation duration and spray-drying inlet temperature on the physicochemical properties of chicken egg white powder. Egg whites were fermented for 4 and 6 h and dried using a Buchi 190 spray dryer at inlet temperatures of 180, 185, and 190 °C. A completely randomized factorial design with two factors and two replications was applied. Data were analyzed using ANOVA followed by Duncan's multiple range test. Spray-drying inlet temperature significantly affected fat content, pH, moisture, and protein content, whereas fermentation time showed limited effects. The combination of 4–6 h fermentation and a 190 °C inlet temperature produced egg white powder with favorable characteristics, including a yield of 3.22–4.83%, color difference of 9.02–10.05, pH of 10.70–10.75, moisture content of 5.64–5.76%, protein content of 78.30–78.74%, ash content of 5.40–5.64%, and particle size of 3.15–3.77 µm. However, pH and fat content did not fully meet Indonesian National Standard (SNI) requirements, indicating that further process optimization is necessary.

1. INTRODUCTION

Eggs are a staple in human diets because of their affordability, high-quality proteins, and functional properties such as foaming and emulsification (Beck *et al*., 2025). In Indonesia, the supply of layer chicken eggs is projected to exceed demand by at least 2026, reaching a surplus of 392.67 thousand tons in that year. However, the perishable nature of eggs, particularly their susceptibility to quality degradation within 17 days, limits their shelf life and market potential. Egg white, which accounts for 57% of the egg mass, is especially valued in the food industry for its protein-driven functionalities, including foaming and gelling. These attributes are primarily attributed to proteins such as globulin, ovomucin, ovalbumin, and conalbumin (Wulandari & Arief, 2022).

To address the perishability of eggs, drying methods have been employed to extend their shelf life. Among these methods, spray drying has gained prominence because it converts liquid egg white into a powder with a uniform particle size and high practicality. Spray-drying eggs into powder solves several practical problems such as (1) extends shelf life from days for fresh/liquid eggs to months/years at ambient conditions by removing water and lowering water activity, (2) improving food safety by combined fermentation and rapid drying reduce pathogens and inhibit microbial growth, (3) reduce logistics cost by reducing weight/volume and improves transport/storage efficiency without refrigeration, (4) increase stability/quality by minimizing thermal damage versus other drying methods, better preserving proteins' foaming, emulsifying, and gelling functions, and (5) consistency in standardizes composition for industrial use, easy dosing and blending. Spray drying transforms perishable liquid eggs into shelf-stable, safe, light-weight, functionally active powders well suited for industrial and nutritional uses (Suhag *et al*., 2025).

Egg white powder offers several advantages, including an extended shelf life, ease of transportation, and reduced perishability (Ma *et al*., 2013). However, the production of high-quality egg white powder requires the optimization of key parameters in the production process, such as fermentation time and drying temperature. The production of high-quality egg white powder requires precise control of processing parameters. The Indonesian National Standard (SNI 01-4323-1996) specifies benchmarks for moisture (≤8%), ash (≤5%), protein (≥75%), pH (6.5–7.5), and microbial safety. Prior work by Herawati *et al*. (2024) showed that spray-dried egg whites can meet these criteria under specific conditions (e.g., 140 °C inlet temperature), achieving a protein content of 83.09% and a foaming capacity of 29.76%. Despite the advantages of spray drying, the influence of fermentation processes using *Saccharomyces cerevisiae* from yeast bread at different fermentation time on the quality of egg white powder need further explored. Fermentation can enhance protein functionality by altering protein structure, such as improving solubility and foaming stability. However, the optimal fermentation duration and drying temperature for achieving superior egg white powder characteristics have not yet been established.

This study aimed to evaluate the effects of fermentation time and spray-drying temperature on the quality of chicken egg white powder. Hyphotheses of this experiment are fermentation time, inlet temperature and their interaction have significant effect on egg powder properties. The findings of this study provide insights into the optimal processing conditions for producing high-quality egg white powder, thereby contributing to the food processing industry by enhancing product quality and consistency.

2. MATERIALS AND METHODS

The primary materials used in this study were chicken eggs and yeast bread. The equipment included a Buchi 190 spray dryer, mixer, oven, pH meter, digital scale, chromameter, furnace, Kjeldahl apparatus, Soxhlet extractor, and scanning electron microscope (SEM).

2.1. Procedure

Eggs were obtained from layer chicken farms in Bogor, with an average weight of 62.5 g. The eggs were washed, sorted, and selected to ensure they were free of cracks, convex yolks, and stains. After cleaning, the eggs were cracked open, and the yolk was separated from the white. Only egg white was used in the present study.

The egg whites were homogenized using a mixer for 1 min. Fermentation was performed using yeast strain of *Saccharomyces cerevisiae* by adding bread yeast to 0.3% egg white weight. Fermentation take place at room temperature and 75 % relative humidity for 4 and 6 h. After fermentation, the egg whites were dried using a Buchi 190 spray dryer with a capacity of 1 L/h. The drying process was performed at inlet temperatures of 180, 185, and 190 °C. The processing conditions of spray drier were outlet temperature of 90 ℃, feed rate of 10 ml/min and atomizing air of 936 L/h by using 0.5 mm nozzle diameter. No filler or carrier agent was added during the drying process, as the protein content of egg white was sufficient to support powder formation. Sosnowska *et al*. (2023) reported that the processing conditions directly affect the outlet temperature, air velocity, drying stability, and quality parameters of the resulting protein powder. The resulting egg white powder was analyzed to determine its quality parameters, including yield, color (L value), pH, moisture, ash, protein, fat, and particle size. The flow of the research process is shown in Figure 1.

The experimental design used in this study was a completely randomized factorial design (CRD) with two factors and two replications per treatment. Factor A was the duration of egg white fermentation before drying (4 and 6 h). Factor B is the dryer inlet temperature (180, 185, and 190 °C). Future studies are recommended to employ at least three replications to improve the statistical reliability and validity of the results.

The additive linear model representing this design is presented in Equation (1).

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} \quad (1)$$

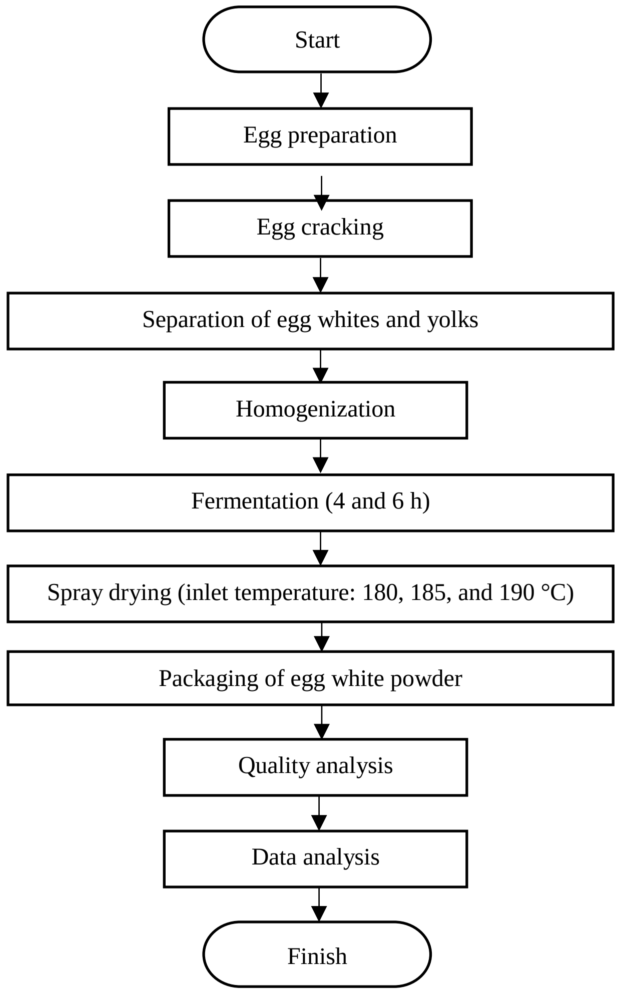

Figure 1. Flowchart of the Research Procedure

where Y_{ijk} = observation on the k^th^ experimental unit with the combination of treatment level *i* of factor A and level *j* of factor B; μ = population mean; α_i = effect of level *i* of factor A (fermentation duration;, β_j = effect of level *j* of factor B (dryer inlet temperature; $(\alpha\beta)_{ij}$ = interaction effect between levels *i* and; ε_{ijk} = random error associated with the k^{th} experimental unit under the treatment combination *ij*.

The collected experimental data were analyzed using analysis of variance (ANOVA) with SPSS software. If a significant effect ($p < 0.05$) was detected for any factor or interaction, Duncan's multiple range test (DMRT) was applied for post-hoc comparisons to determine the differences between the treatment levels.

2.2. Quality Analysis

The quality parameters observed in this study for egg white powder included yield, water content, pH, color, ash content, protein content, fat content, and particle size.

2.2.1. Yield

The yield was determined by comparing the weight of the spray-dried egg white powder with the initial weight of the liquid egg white sample. The yield percentage was calculated using Equation (2) (Abreha *et al*., 2021).

$$Yield\ (\%) = \frac{mass\ of\ egg\ white\ powder\ (g)}{mass\ of\ egg\ white\ (g)} \times 100\% \quad (2)$$

2.2.2. Water Content

The water content was analyzed using the oven method (AACC International Method 44-15.02). A 2 g sample of egg white powder was placed in a cup of known weight and oven-dried at 105 °C for 24 h. After drying, the samples were cooled in a desiccator and weighed. The water content was calculated using Equation (3) (Abreha *et al*., 2021).

$$MC\ (\%) = \frac{W_1 - W_2}{W_1 - W_C} \times 100\% \tag{3}$$

where MC = Water content in the material, W_1 is the sample mass before the oven + porcelain crucible (g), W_2 is the sample mass after the oven + porcelain crucible (g), and WC is the mass of the porcelain crucible (g).

2.2.3. pH

The pH was measured using a potentiometric method. A 1-gram sample of egg white powder was dissolved in 70 mL of distilled water (AOAC, 2019). The pH of the solution was measured using a pH meter.

2.2.4. Color

A few grams of egg white powder were placed in a sample cup and leveled off. The color of the sample was measured using a chromameter, yielding $L*$, $a*$, and $b*$ values, where $L*$ is brightness (higher values indicate higher brightness), $a*$ is red for positive values, and green negative values, $b*$ is yellow for positive values, and blue for negative values. The change in color was calculated based on the color difference (ΔE) using the formula in Equation (4) (Mogol & Gökmen, 2019).

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \tag{4}$$

2.2.5. Ash Content

The ash content was determined using a direct ashing method. A 5 g sample was placed in an ash cup of known weight, burned on a stove until smoke-free, and then placed in an ashing furnace at 600 °C for 2 h. The ash content was calculated using Equation (5) (AOAC, 2019).

$$AC\ (\%) = \frac{W_1 - W_2}{W_1 - W_C} \times 100\% \tag{5}$$

where AC is the ash content (%), W_1 is the sample mass before ashing + porcelain crucible (g), W_2 is the sample mass after ashing + porcelain crucible (g), and WC is the mass of the porcelain crucible (g).

2.2.6. Protein Content

Protein content was analyzed using the Kjeldahl method, which involves three stages of analysis.

1. Destruction stage: A 0.5 g sample was placed in a Kjeldahl flask, and selenium grains and 3 mL of H_2SO_4 were added. The mixture was heated to 410 °C until it became clear.
2. Distillation stage: The cooled solution was mixed with 50 mL of distilled water and 20 mL of 40% NaOH and distilled. The distillate was collected in an Erlenmeyer flask containing 25 mL of 2% H_3BO_3 and a Bromcresol green/methyl red indicator. Distillation was continued until approximately 15 mL of distillate was collected.
3. Titration stage: The distillate was titrated with HCl until the solution turned pink. The protein content was calculated using Equation (6) (AOAC, 2019).

$$N_2(\%) = \frac{ml\ HCl\ sample - ml\ HCl\ blank}{mg\ sample} \times N\ HCl \times 14.07 \times 100\%$$

$$\text{Protein content } (\%) = \%\ \text{N}_2 \times 6.25 \tag{6}$$

2.2.7. Fat Content

Fat content was measured using the Soxhlet method. A 2 g sample was wrapped in filter paper and placed in a Soxhlet extractor. The sample was rinsed with a fat solvent, and the fat flask was heated at 40 °C for 6 h until the solvent in the flask was clear. The flasks were oven-dried until their weights stabilized. The fat content was calculated using Equation (7) (AOAC, 2019).

$$FC\ (\%) = \frac{W_2 - W_1}{W_S} \times 100\% \tag{7}$$

where FC = fat content (%), W_1 = initial mass of the measuring flask (g), W_2 = final mass of the measuring flask (g), and WS = mass of the sample (g).

2.2.8. Particle size

The particle size was analyzed using scanning electron microscopy (SEM). The SEM imaging parameters were using accelerating voltage of 3 kV, detector of secondary electrons (SE) and carbon coating to prevent electron charging. The samples were placed on a prepared stage and observed at a magnification of 20,000X. The particle diameters were measured using ImageJ software. For each treatment, 35 particles were randomly selected to measure their diameters.

The better treatment was determined using a scoring system. Each quality parameter was ranked from 1 to 6, with the highest score assigned to the better result. The highest values were favorable for yield, brightness, and protein content, and the lowest values were favorable for water, ash, fat, and particle sizes. For pH, the score was based on proximity to the quality standard. The scores for all parameters were summed, and the treatment with the highest total score was considered the better.

3. RESULTS AND DISCUSSION

3.1. Quality of Egg White Powder

The quality of the egg white powder was assessed based on various parameters, including the yield, brightness, pH, water, ash, protein, fat, and particle size. The data from the quality analysis are shown in Table 1. The yield of egg white powder showed minimal variation across the tested conditions, indicating that the drying temperature and fermentation time did not significantly affect this parameter. However, a slight increase in yield was observed at higher drying temperatures, which may be attributed to the enhanced water removal efficiency during the drying process. Moreover, the results of the analysis showed that the fermentation time only affected the fat content, whereas the dryer inlet temperature affected the water content, pH, protein content, and fat content of the samples. The interaction between fermentation time and inlet temperature had a significant effect on fat content.

Table 1. Results of egg white powder quality analysis

Parameter	Fermentation Time 4 h			Fermentation Time 4 h		
	Drying Temperature (°C)			Drying Temperature (°C)		
	180	185	190	180	185	190
Yield (%)	3.48±1.33^{a}	3.50±0.61^{a}	4.83±0.91^{a}	3.66±1.14^{a}	1.96±0.25^{a}	3.22±1.12^{a}
ΔE	8.56±0.42^{b}	7.31 ± 0.12^{b}	9.02±1.14^{ab}	11.79±1.37^{a}	9.54 ± 0.47^{ab}	10.05±0.35^{ab}
pH	10.95±0.07^{a}	10.80±0.14^{a}	10.70±0.00^{b}	11.00±0.00^{a}	10.95±0.07^{a}	10.75±0.07^{b}
Water Content (%)	8.04±0.98^{a}	7.34±0.49^{b}	5.76±0.55^{b}	7.64±0.79^{a}	6.07±0.05^{b}	5.64±0.39^{b}
Ash (%)	5.56±0.06^{a}	5.72±0.17^{a}	5.64±0.40^{a}	5.62±0.00^{a}	5.89±0.16^{a}	5.40±0.26^{a}
Protein (%)	75.46±1.13^{a}	76.94±0.89^{b}	78.74±0.33^{b}	74.44±0.17^{a}	78.22±0.52^{b}	78.30±0.82^{b}
Fat (%)	12.44±0.01^{b}	12.69±0.03^{b}	12.64±0.04^{b}	7.96±0.08^{a}	7.38±0.07^{a}	12.42±0.08^{b}
Diameter(μm)	3.41±2.30^{a}	3.90±3.42^{a}	3.77±3.03^{a}	3.17±2.49^{a}	3.13±2.71^{a}	3.15±2.52^{a}

*Values with the same superscript in the same row are not significantly different based on Duncan's test.

3.1.1. Yield

The yield of egg white powder reflects the efficiency of the process and is determined by comparing the weight of the egg white powder produced with that of the raw material used. In this study, the total yield, which included both fine and coarse yields, ranged from 1.96% to 4.83%, as shown in Figure 2. The low yield is due to the poor condition of the nozzle, which prevents the liquid from being atomized properly, causing some of it to be wasted. The fermentation time and inlet temperature did not have a statistically significant effect on the yield. However, the highest yield (4.83%) was obtained after 4 h of fermentation at an inlet temperature of 190 °C, whereas the lowest yield (1.96%) was recorded after 6 h of fermentation at 185 °C. These findings suggest that higher drying temperatures may improve fine yield by enhancing water removal and reducing powder adhesion to chamber walls (Hidayat *et al*., 2024). Longer fermentation times may lead to reduced material mass due to glucose breakdown into carbon dioxide and ethanol (Hertamawati & Muhammad, 2020; Santosa & Santosa, 2021). Suboptimal nozzle settings affect the spray angle and increase wall impingement, directly decreasing yield (Samborska *et al*., 2022).

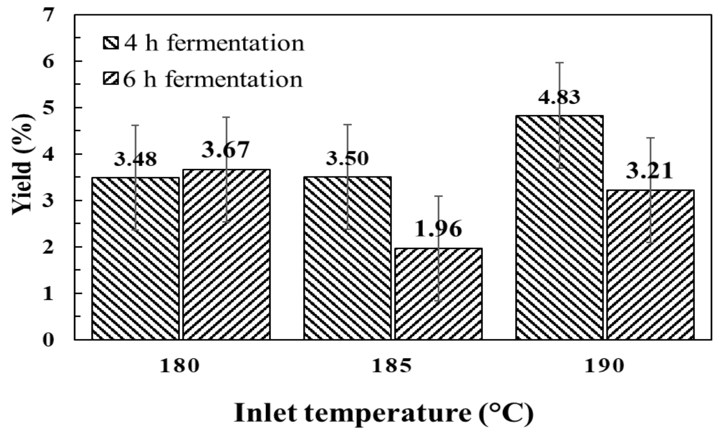

Figure 2. Effects of fermentation time and inlet temperature on egg white powder yield

3.1.2. Color

The color parameters of egg white powder are important for commercial purposes. There is a difference in color between the egg powder in the cyclone and the egg powder in the chamber, as shown in Figure 3. The egg powder in the cyclone has finer particle size and a brighter color compared to the powder in the chamber. The color of the egg white powder darkened with increasing treatment severity (Boreddy *et al*., 2016). In this study, the total color difference (ΔE) was calculated and compared with that of standard egg white powder without fermentation. The ΔE value serves as a useful measure for detecting differences in human color perception; the higher the value, the more noticeable the color difference will be to an observer compared to the color reference. Total color difference (ΔE) value of 1 is defined as the just noticeable difference (JND), meaning that it is the threshold at which a trained observer can perceive a color difference between two objects (Mogol & Gökmen, 2019). A ΔE value in the range of 4–8 was more readily perceived but was still considered acceptable by the observers.

In this study, the ΔE values ranged from 7.31 (A1B2) to 11.79 (A2B1), indicating a clearly noticeable color difference from the reference egg white powder. Using the same egg white powder standard, Herawati *et al*. (2024) also reported dE values of 8.56 for samples subjected to pasteurization and spray drying, and 9.42 for samples without

(a) Egg white powder in the cyclone

(b) Egg white powder in the chamber

Figure 3. Egg white powder produced by spray drying

pasteurization and dried by freeze-drying. These values fell outside the acceptable range for trained observers, indicating that further adjustments are needed to ensure that the color difference does not deviate significantly from the standard reference of egg white powder.

The ANOVA test results showed that fermentation time significantly affected the changes in dE values. Changes in dE values also indicate color changes in egg white powder, one of the causes being the Maillard reaction. The Maillard reaction occurs when reducing sugars (such as glucose) and amino groups (from proteins) react at high temperatures, resulting in color changes, specifically, browning. Fermentation reduces the glucose content in egg whites, thereby minimizing the color changes caused by the Maillard reaction. In this study, the fermentation time affected the glucose content, which in turn influenced the color changes in the egg white powder. This finding is consistent with that of Azizah *et al*. (2022), who fermented egg white powder with various concentrations of *Lactobacillus bulgaricus* and observed differences in color. The higher the concentration of *Lactobacillus bulgaricus*, the greater the lightness (L^*) value observed in the egg white powder.

3.1.3. Water Content

Water content is the percentage of water retained in egg white powder, and it is a critical indicator of product shelf life and microbial stability. The results showed that the water content of fresh egg white was 86.87%. In this study, the water content of egg white powder ranged from 5.64% to 8.04%. According to SNI 01-4323-1996, the maximum allowable water content for egg white powder is 8%, and most samples, except A1B1 (8.04%), meet this standard.

The highest water content was observed in treatment A1B1 (4 h of fermentation at 180 °C), whereas the lowest was recorded in treatment F (6 h of fermentation at 190 °C). The data indicated that the inlet temperature significantly influenced the water content, whereas the fermentation time and its interaction with the inlet temperature did not have a significant effect. Higher inlet temperatures led to a notable decrease in water content owing to more efficient moisture evaporation during drying (Aisah *et al*., 2021).

Prolonged fermentation also indirectly influences the water content by converting bound water within the egg matrix into free water, which evaporates more readily (Nisa & Wardani, 2016). This explains the tendency for lower water content at longer fermentation times, although this effect was not statistically significant. Maintaining proper nozzle atomization and controlling the drying conditions are essential for achieving consistent water content and preventing product clumping or microbial growth in the final product.

3.1.4. pH

The pH of egg white powder indicates the acidity or alkalinity of the product. In this study, the pH ranged from 10.70 to 11.00, which exceeds the recommended range of 6.5 to 7.5 according to SNI 01-4323-1996. The highest pH (11.00) was observed in A2B1, whereas the lowest pH (10.70) was observed in A1B3. This elevated pH may be due to the initial high pH of raw egg white (9.27), which increases during fermentation and drying. Fermentation time did not significantly affect the pH, whereas the drying temperature had a significant impact.

The increase in pH during fermentation is linked to the breakdown of glucose into carbon dioxide and ethanol. When carbon dioxide is released during the drying process, it leads to a relative increase in alkalinity. Conversely, higher drying temperatures can cause the decomposition of materials that produce acidic by-products, slightly lowering the pH (Azizah *et al*., 2022; Hu *et al*., 2025). This explains why the pH trend is inversely proportional to the drying temperature. To meet quality standards, post-processing adjustments, such as the addition of citric acid, can be applied to lower the pH to align it with regulatory guidelines.

Hu *et al*. (2025) demonstrated pH changes resulting from temperature variations during spray drying. Their experiment showed an increasingly alkaline pH ranging from 10.26 to 10.55, consistent with the present study, which produced pH values between 10.70 and 11.00, which were classified as more alkaline values. Hu *et al*. (2025) explained that exposure to high temperatures can cause the side chains of basic amino acid residues within protein molecules to become exposed during the spray drying process. Consequently, the pH of the egg white powder became more alkaline than that before drying. However, the resulting high pH in this research indicating the need for further optimization of the processing conditions.

3.1.5. Ash Content

Ash content represents the mineral residue remaining after combustion and serves as an indicator of the mineral concentration in the egg white powder. According to SNI 01-4323-1996, the maximum allowable ash content of egg white powder is 5%. In this study, the ash content values ranged from 5.40% to 5.89%, with the highest ash content observed in treatment A2B2 and the lowest in treatment A2B3. These values exceeded the SNI standard and were higher than those reported in previous studies, such as the 1.6% reported by Hertamawati & Muhammad (2020). Hertamawati & Muhammad (2020) used a low-temperature oven drying treatment at 58 °C for 24 hours, resulting in lower ash content. Slow drying allows volatile compounds and soluble components to evaporate simultaneously with water, contributing to low inorganic residue after combustion. In contrast, high-temperature spray drying causes rapid evaporation of water without evaporating the mineral components. Consequently, the mineral content was trapped in the powder structure, resulting in a higher ash content relative to the dry mass. High-temperature spray drying causes rapid evaporation of water without evaporating mineral components, trapping inorganic residues in the powder structure (Abreha *et al*., 2021; Zhang *et al*., 2023).

The elevated ash content may have resulted from a higher initial mineral content in the raw material or from potential contamination during processing. Fluctuations in ash content across different treatments suggest that small variations in drying and handling conditions can influence final ash levels. Although fermentation time and drying temperature did not show a statistically significant effect, Sudarmadji *et al.* (1989) noted that higher drying temperatures could increase ash content owing to greater evaporation and concentration of minerals.

3.1.6. Protein Content

Proteins are crucial macronutrients that play a role as building and regulatory substances in the body. According to SNI 01-4323-1996, the minimum protein content of egg white powder is 75%. In this study, the protein content ranged from 74.44% to 78.30%. The highest protein content (78.30%) was recorded in treatment A1B3 (6-hour fermentation at 190 °C), whereas the lowest (74.44%) was observed in treatment A2B1 (6-hour fermentation at 180 °C). However, all samples, except for treatment D, met the SNI protein content standard.

The analysis showed that drying temperature significantly affected protein content, whereas fermentation time and its interaction with inlet temperature did not. Herawati *et al*. (2024) observed an increase in protein content during spray drying, with values of 79.73% without pasteurization and 83.09% with pasteurization. The increase in protein levels at higher drying temperatures can be attributed to the reduction in moisture content, which increases the relative concentration of proteins in the powder. Higher drying temperatures increased protein concentration due to moisture removal (Herawati *et al*., 2024; Sun *et al*., 2021). Partial denaturation and structural rearrangements under thermal treatment contribute to surface hydrophobic exposure and powder stabilization (Beck *et al*., 2025; Hu *et al*., 2025; Wang *et al*., 2022). However, excessively high temperatures can denature proteins and potentially affect their functions. Hu *et al*. (2025) demonstrated that spray drying causes partial denaturation of proteins, characterized by the exposure of hydrophobic groups within the egg white powder and aggregation due to hydrophobic regions, which are normally hidden and become exposed on the surface.

During fermentation, protein levels can change due to the breakdown of complex proteins into simpler ones. Some studies suggest that longer fermentation times can increase free amino acid levels, which may explain these slight variations. However, Anggo *et al*. (2014) noted that extended fermentation may also lead to protein loss, as peptides form volatile compounds. Maintaining a balance between the drying temperature and fermentation time is essential for preserving protein integrity while maximizing the protein concentration. This balance ensures the production of high-quality protein-rich products that are suitable for various applications.

3.1.7. Fat Content

The fat content in the egg white powder ranged from 7.38% to 12.69%, exceeding the SNI 01-4323-1996 standard of 1%. The highest fat content (12.69%) was observed in treatment A1B2 (4-hour fermentation at 185 °C), whereas the lowest (7.38%) occurred in treatment E (6-hour fermentation at 185°C). The analysis showed that fermentation time, drying temperature, and their interaction had a significant effect on fat content. Residual yolk contamination during separation contributes to higher lipid levels (Wulandari & Arief, 2022). Fermentation time and drying temperature significantly influenced fat content, with yeast utilizing lipids during initial fermentation stages (Islami *et al*., 2022).

Herawati *et al*. (2024) reported fat content ranging from 0.03% to 0.31% in egg white powder processed without fermentation (but with pasteurization) using different drying methods. Similarly, Hidayat *et al*. (2024) reported a fat content of 0.17% in egg white powder produced by dry-drying. These findings suggest that fermentation processes and drying methods do not significantly affect the fat content of egg white powder. This is further supported by Wiyantina *et al*. (2017), who explained that all fat is contained in the egg yolk, along with 50% of the total protein content, whereas egg whites contain five types of proteins and only a small amount of carbohydrates. Conversely, in the present study, the fat content ranged from 7.38% to 12.69%, which was considerably higher than the fat content of egg whites. High fat content may result from incomplete separation of the egg yolk during the preparation process, as residual yolk can contribute to higher lipid levels in the final product. The observed decrease in fat content at longer fermentation times may be explained by the consumption of fat by yeast as an energy source during the early stages of fermentation (Islami *et al*., 2022). Over time, yeast activity can lead to lipid synthesis; however, this effect varies depending on the conditions.

3.1.8. Particle Size

The particle size of egg white powder is a key parameter affecting its solubility and rehydration. In this study, the particle size ranged from 0.87 to 14.85 µm, with an average size of 3.42 µm. Treatment A2B2 produced the smallest average particle size (3.13 µm), whereas treatment A1B2 yielded the largest average particle size (3.90 µm). These sizes were finer than those of typical spray-dried powders, which generally range from 10 to 100 µm (Samborska *et al*., 2022). This striking difference can be explained by the effect of the pretreatment fermentation process applied before drying. This finding is consistent with the recent study by Jia *et al*. (2024), who demonstrated that lactic acid fermentation significantly reduces powder particle size. They reported a decrease in particle size from 2.59 µm (non-fermented control) to as low as 0.76 µm after 12 h of fermentation.

Fine particle sizes enhance the solubility of powders, making them more suitable for rapid dissolution in liquids. Scanning Electron Microscopy (SEM) observations, as depicted in Figure 4, showed that the powder particles were predominantly hollow split spheres. The hollow structure increased the surface area, further contributing to the solubility. Pretreatment fermentation induces protein hydrolysis, lowering viscosity prior to atomization and yielding smaller, uniform droplets (Jia *et al*., 2024).

Overall, the highest yield, pH, and protein content were observed in treatment A1B3 (4 h fermentation at 190 °C). A 4 h fermentation time resulted in superior egg white powder quality compared to a 6-hour fermentation time. Among the tested drying temperatures, 190 °C consistently produced powders with better quality attributes than those at 180 °C and 185 °C.

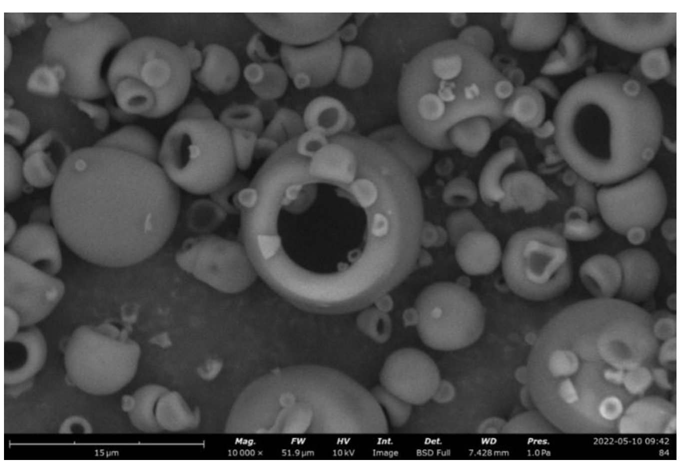

Figure 4. Results of powder particle observations with SEM

Jia *et al*. (2024) explained that the mechanism behind this size reduction is a change in particle morphology due to protein hydrolysis during fermentation. This process changed the particle structure from its original round and smooth shape to a smaller, more uniform, and depressed structure. The hydrolysis and breakdown of solid components during fermentation likely produce a similar effect, resulting in a lower solution viscosity prior to atomization. A lower viscosity allows the nozzle to create finer and more uniform droplets, ultimately producing powders with smaller particle sizes after they are dried. Therefore, the finer particle size in this study was not only a result of the drying parameters but also a direct consequence of the fermentation pretreatment, which has the potential to enhance product solubility.

This study highlights the synergistic effect of short-duration fermentation using *Saccharomyces cerevisiae* combined with high-inlet-temperature spray drying on chicken egg white powder without adding carrier agents. The novelty lies in demonstrating that pre-drying fermentation significantly reduces powder particle size to micro-scale levels (approx. 3.1–3.9 μm) through partial enzymatic and protein structural modification, thereby enhancing structural uniformity and potential rehydration. This research contributes valuable insights into optimizing low-cost preservation methods for surplus egg production in developing food processing industries.

4. CONCLUSIONS

The fermentation time, spray dryer inlet temperature and their interaction significantly affected the color changes, moisture content, protein content, and fat content. These treatments did not significantly affect yield, pH, ash content, and particle diameter. Fermentation for 4–6 h and spray-drying inlet temperature of 190 °C produced egg white powder with relatively favorable physicochemical characteristics and fit the Indonesian National Standard (SNI) based on moisture content (5.64–5.76%) and protein content (78.0–78.74%). However, the resulting pH and fat content did not fully comply with the SNI requirements, indicating the need for further optimization of the processing conditions. Further research should focus on scaling up to the pilot-plant scale and exploring the use of acid additives to achieve pH and fat content compliance in the final product. Additionally, similar studies should be conducted using egg yolks or mixtures to broaden their scope of application.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE MANUSCRIPT PREPARATION

Not applicable. The authors did not use any generative AI tools or services in the preparation of this manuscript. All content is entirely the intellectual work of the authors.

AUTHOR CONTRIBUTIONS

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
RH	✓	✓								✓				✓
MIR			✓		✓				✓		✓		✓	
OFB				✓		✓						✓		
LON		✓						✓						
UAH							✓					✓		

C: Conceptualization	Fo: Formal Analysis	O: Writing - Original Draft	Fu: Funding Acquisition
M: Methodology	I: Investigation	E: Writing - Review & Editing	P: Project Administration
So: Software	D: Data Curation	Vi: Visualization	
Va: Validation	R: Resources	Su: Supervision	

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