JTEP Jurnal Keteknikan Pertanian,
Vol. 14 No. 1, p 49-63, 2026
P-ISSN 2407-0475 E-ISSN 2338-8439

Available online:
http://journal.ipb.ac.id/index.php/jtep
DOI: 10.19028/jtep.014.1.49-63

Research Article

Optimization of Foaming and Filling Agents in Foam-Mat Drying Method for Kombucha Powder Production

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Article Info

Submitted: 9 February 2026
Revised: 26 March 2026
Accepted: 28 March 2026
Available online: 7 April 2026
Published: March 2026

Keywords:
CMC, foam-mat drying, kombucha powder, maltodextrin, tween-80.

How to cite:
Widiaputri, F. F., Mardjan, S. S., & Widayanti, S. M. (2026). Optimization of Foaming and Filling Agents in Foam-Mat Drying Method for Kombucha Powder Production. Jurnal Keteknikan Pertanian, 14(1): xx-xx. https://doi.org/10.19028/jtep.014.1.49-63.

Abstract

Kombucha is a functional beverage produced by fermenting tea with a symbiotic culture of bacteria and yeast (SCOBY). It is known for its various health benefits but is limited by its short shelf-life. To improve its stability, kombucha can be converted into powder using the foam-mat drying method, the effectiveness of which depends strongly on the formulation of foaming and filling agents. This study aimed to determine the optimal formulation of foaming and filling agents in kombucha. This study evaluated four formulations combining maltodextrin (15% and 20%), Tween-80 (0.25–1%), egg albumen (0–5%), and carboxymethyl cellulose (CMC; 0.3%). The formulation of 500 g kombucha with 15% maltodextrin, 0.3% CMC, 0.5% Tween-80, and 5% egg albumen produced the best results, yielding 14.38% powder with 5.78% moisture, a hue value of 1.32, chroma of 14.80, and whiteness index of 81.84. These findings indicate that the selected formulation is effective in producing kombucha powder with desirable physical properties.

Doi: https://doi.org/10.19028/jtep.014.1.49-63

1. Introduction

Kombucha is a functional beverage made by fermenting tea with a Symbiotic Culture of Bacteria and Yeast (SCOBY). Originating in East Asia, this product spread to Russia during the 20th century. It has traditionally been consumed as a medicinal drink because of its detoxifying and energizing properties (Ernawati, 2017). Recently, this product has entered the consumer market, offering a variety of claimed health benefits for consumers. This beverage contains a range of nutrients, including vitamins B1, B2, B3, B12, and C, as well as acetic, amino, glucuronic, and lactic acids, and antioxidants (Puspitasari et al., 2017). Several reported benefits of this beverage include boosting the immune system and exhibiting antibacterial, anticarcinogenic, and anti-inflammatory effects (Mardiana et al., 2022).

Despite these benefits, kombucha faces challenges in terms of storage stability. Liquid or ready-to-drink kombucha may degrade in quality if not stored appropriately. Prolonged storage of this beverage can lead to further fermentation, affecting its flavor characteristics. One alternative to overcome this issue is to convert this beverage into powder form. Powdered products offer several advantages, including greater practicality, maintained product quality, and extended shelf life (Aslamiyah et al., 2019).

The foam-mat drying method is a commonly used drying technique for powdered beverage production. It offers several advantages over other drying methods, such as its simplicity, cost-effectiveness, and relatively low drying temperature (50–80 °C), which helps preserve the nutritional characteristics and organoleptic quality of the dried product (Nilna et al., 2021). This method has been widely applied to dry products, such as milk, yogurt, fruit and vegetable extracts, egg albumin, and coffee (Kumar et al., 2023). However, its application in kombucha drying remains limited. A critical factor in this method is the formulation of the foaming and filling agents, which strongly influences the foam stability and drying efficiency. Therefore, this study aimed to determine the optimal formulation of foaming and filling agents to produce kombucha powder with desirable physical and quality characteristics.

2. Material and Methods

2.1 Materials

Kombucha was prepared from a green tea solution containing 10% (w/v) sucrose. The liquid was inoculated with a SCOBY (9–10 cm in diameter and 0.5–0.7 cm thick) along with 200 mL of starter culture and subsequently fermented for 7 days. The kombucha stock was prepared periodically as required for the formulation experiments. The foaming and filling agents used were maltodextrin, Tween-80, carboxymethyl cellulose (CMC), and egg albumen. The equipment used included an oven (SNOL 120/300 LSN11), a mixer (Philips HR1538/60, 200 W), trays lined with baking mats or heat-resistant plastic, a blender (Philips HR2115), a plastic spatula, and an 80-mesh sieve.

2.2 Experimental Design

This study was conducted using a Completely Randomized Design (CRD) with a single factor and two replications. Four formulations were used in the experiment: Formulation A was based on the study by Naufal et al. (2022), while Formulations B, C, and D were adjusted based on the characteristics of the produced kombucha. The factor examined was the variation in Tween-80 concentration, whereas the other agents (maltodextrin, egg albumen, and carboxymethyl cellulose/CMC) were maintained at predetermined levels. Although the equipment capacity was limited during the process, the same oven and mixer were used for all formulations, ensuring homogeneous experimental conditions. The formulations used in this study are presented in Table 1.

Table 1. Formulation.

Formulation	Kombucha (g)	Maltodextrin (%)	Tween-80 (%)	CMC (%)	Egg Albumen (%)
A	500	20	1	0.3	0
B	500	15	1	0.3	5
C	500	15	0.5	0.3	5
D	500	15	0.25	0.3	5

Each formulation underwent both preliminary trials and a validation stage, where only formulations that produced satisfactory foam mixtures proceeded to the drying process. The preliminary trial was conducted in a single batch as an initial test, and formulations that met the criteria were validated in two batches. Objective observations were performed to evaluate the feasibility of the foam mixtures obtained from each formulation. A foam sample was considered suitable for drying if the kombucha was blended entirely with the foaming and filling agents and exhibited an appropriate viscosity, neither too thin nor too thick. The main parameter evaluated in this study was the final yield after drying the samples. The selected final formulation was then used for large-scale production of kombucha powder.

2.3 Foaming and Drying Process

The foaming process was performed for each formulation, with slight variations in the order of ingredient addition. The first process was applied to Formulation A following a general mixing procedure. In contrast, the second process was used for Formulations B, C, and D, which were adjusted based on the observations from the initial process.

For Formulation A foaming process began with the addition of kombucha, followed by CMC. The mixture was stirred at a low speed for approximately 5 min and then continued at a high speed for approximately 10 min until homogeneous. Maltodextrin was gradually added while mixing at medium speed, followed by the slow addition of Tween-80 for about 1–2 min. The mixture was then whipped again at high speed for approximately 15 min until a stable foam was formed. For Formulations B, C, and D, the process began with the preparation of a premix of maltodextrin and CMC, which was then combined with kombucha. The mixture was then stirred at high speed for approximately 10 min until homogeneous. Tween-80 was gradually added while mixing at low speed, followed by egg albumen for approximately 1–2 min. The mixture was then whipped again at high speed for approximately 15 min until a uniform foam was obtained.

Foam samples that did not pass the observation stage were considered failed batches and were not subjected to drying. Meanwhile, foam samples that met the required criteria were poured onto trays to a thickness of approximately 2–3 mm (equivalent to 4 ladles per tray). The foam was then dried in an oven at 70°C for six hours. After drying, the sheets were cooled for approximately 10 min before scraping and grinding into powder. The yield of kombucha powder was determined after sieving through an 80-mesh screen.

2.4 Parameters and Data Analysis

The main parameter observed in this study was the yield of each formulation after it was dried. For the final kombucha powder formulation, the parameters measured included yield, moisture content (determined by oven drying (AOAC 2012)), and color, which was analyzed using a colorimeter based on the Hunter color system (L, a, and b values). The data were then processed to calculate the hue, chroma, and whiteness index values (Fadhlurrohman et al., 2023). Additional parameters observed as supporting data included the antioxidant activity of green tea and the produced kombucha, determined using the DPPH method (Barzan et al., 2024), vitamin C content measured by titration (Nilna et al., 2021), and the pH of the produced kombucha. Data were analyzed using analysis of variance (ANOVA). When significant differences were detected ($p < 0.05$), Duncan's multiple range test was applied. The results are presented as mean ± SD (n=3).

3. Results and Discussion

3.1 Kombucha Characteristics

The produced kombucha was analyzed for vitamin C content, antioxidant activity, and pH to determine its overall condition. The antioxidant activity of green tea used as a substrate was also analyzed to observe changes during kombucha fermentation. The results of the analyses of green tea and kombucha are presented in Table 2.

Table 2. Results of the analysis of green tea and kombucha.

Parameters	Green Tea	Kombucha
Antioxidant activity / IC_{50} (ppm)	5,912.80	4,087.39
Vitamin C (mg/100g)	-	185.05
pH	-	3.20

The green tea used in this study had an IC_{50} value of 5,912.80 ppm, which decreased to 4,087.39 ppm after processing into kombucha. The reduction in the IC_{50} value of the raw material indicates an increase in antioxidant activity following fermentation. IC_{50} represents the concentration required to inhibit 50% of the DPPH free radicals. Therefore, the lower the IC_{50} value, the higher the antioxidant activity of the sample (Widyasanti et al., 2016). The increase in antioxidant activity is attributed to the formation of free phenolic compounds by microorganisms in the SCOBY during fermentation. The higher the concentration of free phenolics, the greater is the resulting antioxidant activity (Hassmy et al., 2017).

The produced kombucha had a vitamin C content of 185.05 mg/100 g and a pH value of 3.20. In comparison, green tea kombucha produced by (Jakubczyk et al., 2024) had a vitamin C content of 27.174 mg/100 g and a pH of 2.99. During fermentation, the vitamin C content may increase in parallel with enhanced antioxidant activity (Malbaša et al., 2011). The sugars present in the tea solution promote microbial activity and the formation of organic acids during fermentation. The low pH value is attributed to the accumulation of total organic acids produced by SCOBY (Hassmy et al., 2017). Despite its relatively low pH, the kombucha obtained in this study is considered safe for consumption, as kombucha is acceptable when its pH is within the range of 2.5–3.5 (Kamelia et al., 2023).

3.2 Foam Feasibility

The foam mixtures were visually evaluated using a descriptive approach without quantitative measurements to determine their suitability for drying. The parameters observed included the viscosity of the mixture, size of the bubbles formed, volume after whipping, and overall appearance of the whipped foam. Only the foam mixtures that passed the screening stage were subjected to the drying process. The suitability of the foam mixtures is presented in Table 3.

Table 3. Foam feasibility.

Formulation	Parameters				Note
	Viscosity	Bubble Size	Foam Expansion	Mixing Result	
A – trial	High	Small	Slight increase	Well mixed	**Passed**
A – val 1	Low	Small	No increase	Not well mixed	Failed
A – val 2	Low	Small	No increase	Not well mixed	Failed
B – trial	Medium	Small	Slight increase	Well mixed	**Passed**
B – val 1	High	Small	Increase	Well mixed	**Passed**
B – val 2	High	Small	Increase	Well mixed	**Passed**

Formulation	Parameters				Note
	Viscosity	Bubble Size	Foam Expansion	Mixing Result	
C – trial	Medium	Small-medium	Slight increase	Well mixed	**Passed**
C – val 1	Medium	Small	Slight increase	Well mixed	**Passed**
C – val 2	Low	Small-medium	Slight increase	Well mixed	**Passed**
D – trial	Medium	Small-medium	Slight increase	Well mixed	**Passed**
D – val 1	Low	Small	No increase	Not well mixed	Failed
D – val 2	Low	Small	No increase	Not well mixed	Failed

Foam formation depends on several factors, including the composition of the liquid, foaming method, and foaming time. Foam is a colloidal dispersion in which gas is dispersed within a continuous liquid phase of a surfactant. Foams are classified into two types based on the ratio of the dispersed to continuous phases: polyhedral and bubbly liquid foams (Sangamithra et al., 2015). Polyhedral foam has a high dispersed-to-continuous phase ratio, leading to a large number of closely packed bubbles that form a honeycomb-like structure. In contrast, bubbly liquid foam has a low dispersed-to-continuous phase ratio, resulting in bubbles that remain separate and spherical without being pressed against one another. The observations in this study showed that most of the foam samples produced were classified as bubbly liquid foams, with bubbles remaining distinct and not collapsing or merging under pressure.

The stability and capacity of a foam mixture are considered balanced when its viscosity is neither too low nor too high (Kumar et al. 2023). High viscosity is characterized by the adherence of the mixture to the spatula. In contrast, a low viscosity is indicated by the mixture easily dripping off the spatula and not remaining on it for a long time. Based on Table 3, the viscosity of Formulation A preliminary trial was categorized as high, whereas Formulations B, C, and D showed moderate viscosity. The high protein content of egg albumen reduces the surface tension of the mixture as proteins are adsorbed at the air–liquid interface (Kumar et al., 2023). This phenomenon contributed to the decrease in the viscosity of the foam sample.

Higher concentrations of Tween-80 can increase the viscosity of the foam mixture (Shabrina & Khansa, 2022). This observation was consistent with the conditions of Formulations B, C, and D but not with those of Formulation A validation stage. The low viscosity observed in Formulation A validation was presumed to be due to the lower quality of Tween-80 used. Tween-80 may have degraded during the formulation process. Significant degradation of both Tween-20 and Tween-80 stored at room temperature for 24 weeks has been reported, leading to the formation of peroxides and loss of polysorbate content (Kishore et al., 2011). Consequently, the structural instability of Tween-80 results in phase separation and a decrease in its viscosity.

The foam samples produced from each formulation exhibited small-to medium-sized bubbles. Uniformly distributed small bubbles result in a soft foam texture (Hardy & Jideani, 2017). However, foams are naturally unstable because the surface tension acts against the forces required to maintain their structure. This instability can be mitigated by adding CMC. Increasing the CMC concentration has been reported to enhance foam stability in butterfly pea flower foam mixtures, with 0.3% CMC providing 87.47% stability and 0.7% achieving 94% stability (Thuy et al., 2023). This surfactant prevents foam agglomeration and promotes the formation of more stable and long-lasting foams.

Foam expansion refers to the increase in kombucha volume resulting from incorporating air during the foaming process. The foam expansion observed in each formulation during the preliminary trials increased slightly. This was indicated by the upper boundary of the mixture reaching one-third of the mixer head compared to its initial level at the mixer tip. The addition of egg albumen likely influenced the increase in foam expansion size. During foaming, the denaturation of egg albumen proteins promotes the formation of a stable viscoelastic interfacial layer through interactions among nutrient molecules (Indrianti et al., 2023), thereby contributing to increased foam expansion (Thuy et al., 2023).

Foam expansion can also occur due to the addition of Tween-80. Tween-80 increases the amount of foam produced and reduces the surface tension between two phases (Purbasari, 2019). The greater the percentage of Tween-80, the greater the foam expansion. However, this trend was not observed in the foam sample of Formulation A validation stage. A plausible explanation for this is the suboptimal quality of Tween-80, which had been stored for an extended period. Degradation during storage reduces the amount of intact polysorbate, thereby diminishing its surfactant function. Consequently, the foam produced was more fragile and less stable.

The mixing result was the final parameter used to determine the suitability of the foam sample. This parameter refers to the condition of the mixture after it was left to stand for approximately 5 min to observe whether drainage occurred. Drainage is the flow of liquid through foam driven by capillary forces or external factors such as gravity (Salahi et al., 2015). This was indicated by the appearance of the kombucha liquid at the bottom of the mixing container when checked using a spatula. Drainage occurs due to the thinning of the lamella, which separates the liquid phase from the interfacial layer, leading to the collapse of the foam structure (Indrianti et al., 2023).

Based on the results presented in Table 3, the validation stage for Formulations A and D showed uneven mixing results. This was attributed to the suboptimal quality of the foaming agent, Tween-80, which degraded over time. Tween-80 degradation affects the quality of the foam samples produced. In addition, the low Tween-80 concentration in Formulation D may have contributed to the non-uniform mixing, as Tween-80 was unable to bind the foam effectively. Excessively high concentrations of Tween-80 can cause foam instability and rapid bubble collapse (Isabella et al., 2022), whereas low concentrations fail to fully exploit its emulsifying function, resulting in reduced foam formation (Vincentius, 2005).

3.3 Drying Results

The thickness of the foam sample when poured onto the tray affected the drying results. This effect is illustrated in Figure 1, which shows the appearance of the dried foam samples.

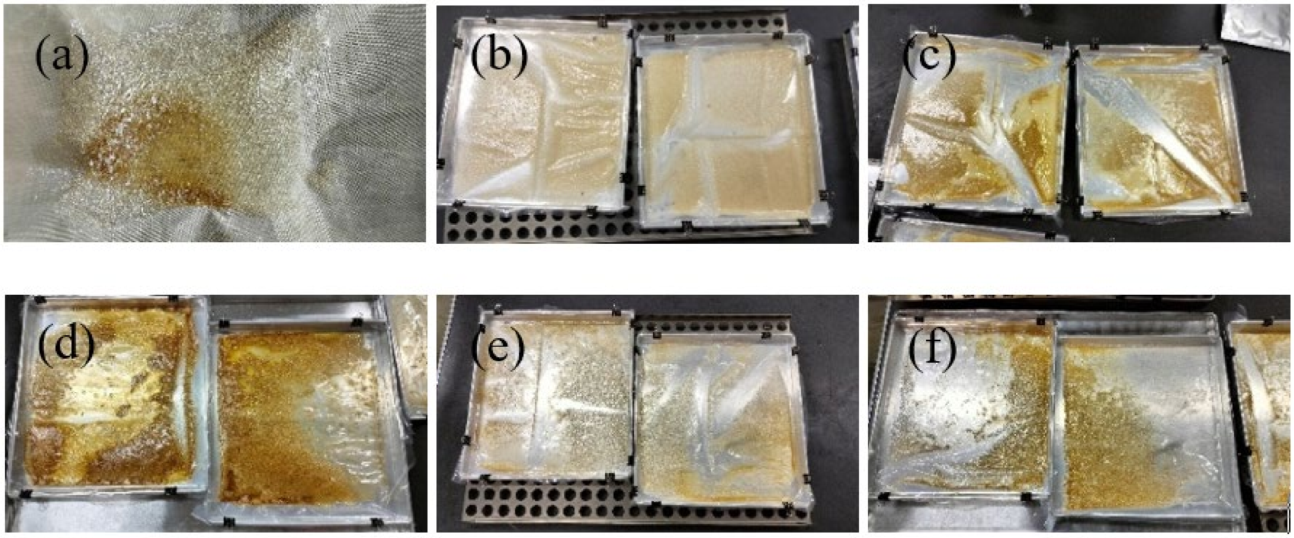

Figure 1. Drying results of foam samples: (a) Formulation A – trial; (b) Formulation B – trial; (c) Formulation C - trial; (d) Formulation D - trial; (e) Formulation B – validation; (f) Formulation C – validation.

The drying results shown in Figure 1 indicate variations in thickness, including thick, moderately thick, and thin regions. This occurred because the tray surface was not level when the foam sample was poured. Although the sample was spread evenly, the tray's movement during transfer into the oven could have caused it to shift and accumulate on one side. The overly thick portions did not dry completely, resulting in a sticky and caramel-like texture. These portions were excluded from the yield calculation and were unsuitable for powder processing.

3.4 Powder Yield

The powder yield was calculated only when the dried product did not exhibit a soapy taste or aroma. Except for the dried mixture from Formulation B during the validation stage, the resulting powders generally had a sweet flavor with a slightly acidic aroma characteristic of kombucha. The sweetness was attributed to the residual sugar retained during drying.

The proportions of filling and foaming agents must be carefully determined, as they influence the consumer acceptability of the final product. Tween-80 has a strong odor and slightly bitter taste, which can reduce consumer preference for the product flavor (Winarti et al., 2024). In the dried mixture of Formulation B during the validation stage, a slightly bitter taste and distinct soapy aroma were detected. Therefore, this batch was excluded from the powder-yield calculation. The powder yields obtained from both the trial and validation stages are presented in Table 4.

Table 4. Powder yield.

Stage	Formulation	Powder Yield (%)
Trial	A	18.71
	B	20.87
	C	14.31
	D	16.23
Validation	C	18.21

The powder yields obtained during the preliminary trial varied considerably, with the lowest yield observed in Formulation C (14.31%) and the highest in Formulation B (20.87%). Although Formulation C had the lowest powder yield during the preliminary trial, it increased to 18.21% during the validation stage. This improvement was likely due to the more uniform thickness of the dried foam compared to that in the preliminary trial, resulting in fewer sticky portions being discarded.

The powder yield of dragon fruit peel kombucha reported by Naufal et al. (2022) using Formulation A 25.76 %. The considerable difference in yield compared to the present study may be attributed to variations in the characteristics of the kombucha and SCOBY used. Similar studies have reported that herbal powders with the addition of 12.5% maltodextrin and 0.5% Tween-80 yielded 11.85% (Wiyono et al., 2024), kesum leaf powder with 15% maltodextrin and 0.5% Tween-80 yielded 12.36% (Mayasari et al., 2023), and soymilk powder with 10% maltodextrin and 1% Tween-80 yielded 15.69% (Purbasari, 2019). The formulation selected for the large-scale production of kombucha powder was determined based on previous results, particularly those related to the powder yield during the trial and validation stages. Accordingly, Formulation C was selected as the most suitable based on the characteristics of the resulting kombucha.

3.5 Aplication of the Selected Formulation

Formulation C was applied to 12 production batches. Overall, the foam mixtures exhibited low to medium viscosity and small to medium bubble sizes, consistent with the conditions observed during the trial and validation stages. All the mixtures exhibited foam expansion and uniform mixing results. The drying process was performed for all batches, and several examples of the dried foam results are shown in Figure 2.

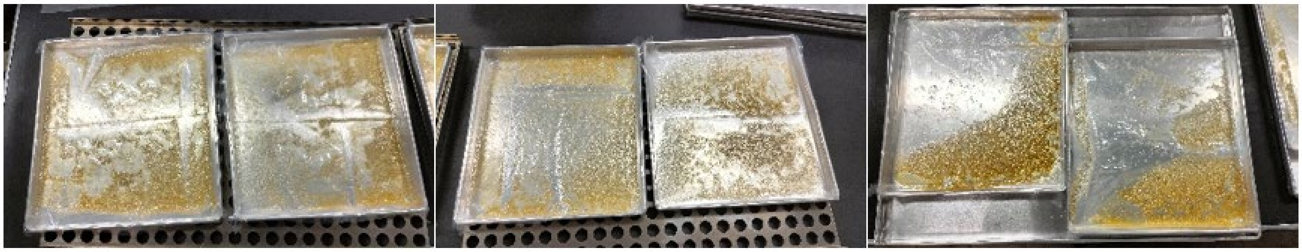

Figure 2. Several examples of the drying results of Formulation C.

The dried mixtures showed no significant differences from those produced during the trial and validation stages. Some uneven areas were still observed; however, the dried mixtures could still be scraped and ground to obtain the final powder yield. The characteristics of the research kombucha powder and its comparison with commercial kombucha powder are presented in Table 5, and their appearance is shown in Figure 3.

The final powder yield was 14.38%, which was comparable to that obtained during the preliminary trial but lower than that observed in the validation stage. The variation in yield may have been caused by the sticky portions of the dried foam that were excluded from the yield calculation. The moisture content of the kombucha powder produced in this study was 5.78 ± 0.08%, whereas that of the commercial kombucha powder was 11.02 ± 0.24%. Statistical analysis showed that the moisture content of the kombucha powder was significantly lower than that of the commercial product ($p < 0.05$), indicating more effective moisture removal under the applied foam-mat drying conditions. The granules of the kombucha powder from this study were finer than those of the commercial product, likely due to the 80-mesh sieving process applied. In contrast, the larger granule size of the commercial kombucha powder may be attributed to the presence of additional ingredients such as sugar.

The hue, chroma, and whiteness index values of the kombucha powder produced in this study were higher than those of commercial kombucha powder. Significant differences ($p < 0.05$) were observed for all color parameters, with kombucha powder exhibiting higher chroma (14.80 ± 0.29) and whiteness index (81.84 ± 0.37). As shown in Figure 3, the kombucha powder used in this study exhibited a yellowish-white color, whereas the commercial powder appeared grayish-white. Color plays an essential role in influencing consumer decisions when selecting products (Rajain & Rathee, 2019). Based on this observation, the difference in color characteristics made the kombucha powder from this study more visually appealing and preferred by the panelists, with an average color preference score of 6.13 on a 7-point scale.

Figure 3. Final powdered products: research kombucha powder (left) and commercial kombucha powder (right).

Table 5. Characteristics of the research kombucha powder and its comparison.

Parameters	Research Kombucha Powder	Commercial Kombucha Powder
Powder Yield (%)	14.38	-
Moisture content (%)	5.78 ± 0.08^b	11.02 ± 0.24^a
Hue	1.32 ± 0.02^a	1.05 ± 0.03^b
Chroma	14.80 ± 0.29^a	5.95 ± 0.36^b
Whiteness index	81.84 ± 0.37^a	78.32 ± 0.24^b

The final powder yield was 14.38%, which was comparable to the yield obtained during the preliminary trial but lower than that observed during the validation stage. The variation in yield may have been caused by portions of the dried foam that were sticky and, therefore, excluded from the yield calculation. The moisture content of the kombucha powder produced in this study was 5.78 ± 0.08%, while that of the commercial kombucha powder was 11.02 ± 0.24%. Statistical analysis showed that the moisture content of the research kombucha powder was significantly lower than that of the commercial product ($p < 0.05$), indicating more effective moisture removal under the applied foam-mat drying conditions. The granules of the kombucha powder from this study were finer than those of the commercial product, likely due to the 80-mesh sieving process applied. In contrast, the larger granule size of the commercial kombucha powder may be attributed to the presence of additional ingredients such as sugar.

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4. Conclusion

The composition and storage of foaming agents, particularly Tween-80, influenced the foam properties. Formulation C, consisting of 500 g kombucha, 15% maltodextrin, 0.5% Tween-80, 0.3% CMC, and 5% egg albumen, was identified as the optimal formulation in this study. The powder yields obtained during the trial, first validation, second validation, and application stages were 14.31%, 17.77%, 18.66%, and 14.38%, respectively. The moisture content and color characteristics of the produced kombucha powder were superior to those of the commercial product, with a moisture content of 5.78 %, hue of 1.32, chroma of 14.80, and whiteness index of 81.84. Future studies should include quantitative analyses of foam properties (viscosity, expansion, and drainage volume) and drying rate calculations to assess process efficiency. The use of oxygen-unexposed Tween-80 is strongly recommended for future formulation experiments to ensure consistent foam characteristics. Comparative evaluations using alternative drying methods, such as spray or drum drying, are also recommended.

5. AI Writing Statement

The author used a Generative AI tool (ChatGPT, version 5.3) to assist in translating the manuscript from Indonesian to English and for language editing. All analyses, data interpretations, and conclusions were conducted independently by the authors.

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