Research Article

Optimizing Dextrin Levels for Enhanced Physicochemical Properties and Microstructure of Sumbawa Mare's Milk Powder

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Abstract | This study explores the potential of adding dextrin to Sumbawa Mare's Milk powder to improve its physical and functional properties. The main objective was to determine the optimal dextrin concentration that improves the physicochemical properties while maintaining the structural integrity of powdered milk. This research used a laboratory experimental method using a completely randomized design (CRD) with four treatments (addition of 15%, 20%, 25% and 30% dextrin) and four replications. In this study, Sumbawa Mare's Milk was dried using the vacuum foam oven drying (VFOD) method at a temperature of 70 °C for 7 hours, the resulting flakes are ground into powder. The research results showed that the addition of dextrin at different levels significantly (P<0.05) affected pH and emulsion stability and highly significantly (P<0.01) influenced water solubility and water content. However, it did not significantly affect (P>0.05) oil holding capacity, water holding capacity, or emulsifying activity in the mare's milk powder. A 15% dextrin concentration resulted in the highest emulsion stability (0.46), as well as the highest water content (5.25%). Meanwhile, the 15% and 25% dextrin treatments produced the lowest values for water solubility, with the lowest solubility observed in the 25% treatment and the highest in the 30% treatment. Field Emission Scanning Electron Microscope (FESEM) analysis revealed that samples with 15% dextrin had more uniform and finer particles compared to samples with 20%, 25%, and 30% dextrin, which exhibited cracked and broken structures. These structural improvements were achieved without reducing carbon content (54.58%) and with the highest nitrogen ratio (3.17%). This microstructural enhancement contributes to better-quality mare's milk powder. The addition of 15% dextrin optimally enhanced the water-holding capacity, solubility, and emulsion stability of Sumbawa mare's milk powder while preventing the formation of lipid bridges and reducing free fat content.

Keywords | Sumbawa mare's milk powder, Addition of dextrin, FESEM analysis, Microstructure, Reconstitution properties

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INTRODUCTION

Horses have played an integral role in human history across various cultures worldwide. Historically, mare's milk has been an essential nutritional source for herders and horse breeders. However, with the discovery of mare's milk as a beneficial alternative for individuals allergic to cow's milk protein, interest in its consumption has grown significantly, reaching approximately 30 million daily consumers. Nevertheless, the contribution of mare's milk to global dairy production remains minimal, accounting for less than 0.1%, compared to cow's milk, which dominates with 83% of global production (Faye and Konuspayeva, 2012). Mare's milk contains high levels of bioactive components such as lactoferrin and lysozyme, which exhibit antimicrobial properties that support the human immune system (Berthon *et al*., 2022; Nurgaziyev *et al*., 2020). Compared to cow's milk, mare's milk has lower casein content and higher whey protein levels, making it easier to digest and more tolerable for individuals with cow's milk allergies (Faye and Konuspayeva, 2012), thus creating promising market prospects.

In Indonesia, Sumbawa horse's milk is well known as a local product that has health benefits and is used in medicine (Hermawati *et al*., 2004; Prastyowati, 2021). However, the distribution of Sumbawa Mare's Milk in liquid form faces major obstacles related to its short shelf life and susceptibility to microbial contamination. Therefore, processing horse milk into powder form is an effective solution, because powdered milk has a longer shelf life (Lang *et al*., 2017), is easy to distribute, and is more practical in storage and use.

The production of milk powder involves drying processes and mixing with other ingredients such as whey powder, sugar, vitamins, minerals, or other fillers like dextrin. Dextrin, which can be used as a filler or carrier in the powdered milk industry due to its low cost, high solubility, and low hygroscopicity, is an excellent choice for improving the physical and chemical qualities of milk powder. Dali *et al*. (2017) reported that adding dextrin to powder can enhance its physical and functional properties while reducing raw material costs. Generally, the carrier content in milk powder should not fall below 50% solids to ensure effective spray drying. However, some studies indicate that producing milk powder with higher milk content in the solids is still feasible. The amount of dextrin used in milk powder formulation is crucial, as insufficient amounts may lead to issues such as sticking to dryer walls, clumping, poor flowability, and reconstitution problems, while excessive amounts are perceived as an imitation of the product.

Although much research has been carried out on horse milk, important aspects related to the characteristics of powdered milk—such as emulsion stability, physicochemical properties, and microstructure—still require further study. This study aims to evaluate the effect of dextrin concentration on emulsion stability, physical properties and microstructure of Sumbawa mare's milk in powder form. It is hoped that the results of this research can provide insight into the use of dextrin to improve the stability and quality of powdered milk products, as well as extend their shelf life.

MATERIALS AND METHODS

Material

This research used Sumbawa Mare's Milk obtained from Curi Mori Karamabura partners. The milk was stored in sterile plastic containers and maintained at a temperature of 4 °C to maintain freshness and prevent microbial growth until the next process. As part of the formulation, Tween 80 Food Grade was used in a concentration of 1% as an emulsifier to ensure homogeneity of mixing of ingredients. Dextrin with a dextrose equivalent (DE) value of 18-20 was chosen because of its high solubility and ability as a filler that can improve the physical properties of the final product.

Experimental Methods and Design

The method used in this research was a Completely Randomized Design (CRD) with 4 treatments and 4 replications, totalling 16 experimental samples. In this study, different concentrations of dextrin were used as a treatment for the production of Sumbawa mare's milk powder. The research design was as follows: P1 (addition of 15% dextrin), P2 (addition of 20% dextrin), P3 (addition of 25% dextrin), P4 (addition of 30% dextrin).

The Process of Making Powdered Sumbawa Mare's Milk using Vacuum Foam Oven Drying (VFOD)

The process of making mare's milk powder using a vacuum foam oven drying was conducted based on the method by Maharani *et al*. (2023). Initially, 200 ml of pasteurized Sumbawa Mare's Milk was weighed, then 1% Tween 80 was added and dextrin with different concentrations (15%, 20%, 25% and 30%) according to the treatment applied. The mixture was homogenized using a mixer for 2-3 minutes until foam forms. Next, the samples were transferred into aluminium trays lined with baking paper, and dried using a vacuum drying oven at 70°C for 7 hours. After the sample dried and turned into glass flakes, the sample was ground using a grinder for 1-2 minutes until it became a fine powder.

Physicochemical Analysis

pH testing was carried out using a pH meter referring to the testing procedure (AOAC, 2000). Solubility testing

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based on Yuwono and Susanto (1998) was carried out with the principle of measuring the amount of sample that does not dissolve within a predetermined time and conditions. The water content was evaluated according to the procedure described by Sudarmadji (1997). Emulsion activity (EA) and emulsion stability (ES) was determined according to the method reported by Selmane *et al.* (2008). Oil holding capacity was carried out according to the Subagio (2006).

Microstructural Analysis

Microstructural analysis using the FESEM/EDX method (*Field Emission Scanning Electron Microscope-Energy Dispersive X- Ray Spectroscopy*) is an instrumental technique used in nano-microscopic research by qualitatively knowing the physiological conditions in samples such as powdered Sumbawa Mare's Milk, the FESEM/EDX analysis results procedure was based on Setyaningsih *et al.* (2017).

Statistical Analysis

The collected data were presents as mean ± standard deviation and analyzed by one-way analysis of variance (ANOVA) to determine the significant differences (P<0.05 and P<0.01). Duncan's multiple range test was performed to measure specific differences between pairs of means. Statistical analysis was carried out using Microsoft Excel Program.

RESULTS AND DISCUSSION

Physicochemical Analysis

pH of sumbawa mare's milk powder: The addition of dextrin at varying levels (15%, 20%, 25%, and 30%) to Sumbawa mare's milk powder showed a significant difference (P<0.05) in pH values. The data in Table 1 show that the pH of the Sumbawa mare's milk powder increased in line with the dextrin level. The highest pH value was found at 30% dextrin addition with a pH value of (3.32±0.05), while the lowest value was found at 15% addition with a pH value of (3.22±0.05). Meanwhile, Duncan's post hoc test indicated that the treatments at 15%, 20%, and 25% were not significantly different. However, all three treatments differed significantly from the 30% dextrin addition. The increase in pH in line with the dextrin addition was also reported in powdered goat milk kefir (Rizqiati *et al.*, 2021).

The increase in pH during the dextrin level addition in Sumbawa mare's milk powder is likely due to an increase in the number of hydroxyl groups in the product. Tari and Retnaningsih (2014), stated that the high hydroxyl content of oligosaccharide/starch compounds like dextrin can neutralize the acid content in the product. Furthermore, dextrin is a polysaccharide that can interact with proteins through hydrogen bonds or steric effects. This interaction may alter the milk solution's properties, such as the activity of H^+ ions, thus increasing the pH and improving the solubility of the milk.

Although an increase in pH was observed during the dextrin addition process, overall, the pH of the mare's milk remained within standard limits, with values ranging from 3.2 to 3.8 (Park *et al.*, 2006), while in this study, it ranged from 3.22 to 3.32. This pH difference is due to the higher lactose content and the different protein composition between mare's milk and cow's milk. Mare's milk contains more whey protein (about 20%), while cow's milk contains more casein, which affects the pH and physical stability of the milk. Meanwhile, the findings of Rizqiati *et al.* (2021) indicated that the addition of low molecular weight dextrin can lower the pH because more hydrolyzed dextrin tends to be more acidic compared to higher molecular weight dextrin. Schuck *et al.* (2016) also added that higher molecular weight dextrin could help maintain pH stability during storage.

Table 1: The effect of dextrin concentration on physical properties.

Variable	Dextrin Level (%)				p-Value
	15	20	25	30	
pH	3,22[a]± 0,05	3,27[ab] ±0,05	3,22[a] ±0,05	3,32[b] ±0,05	0,044
Water solubility (%)	73,65[b] ±2,08	77,11[c] ±1,03	68,70[a] ±0,67	86,54[d] ±1,02	0,000
Water Content (%)	5,25[c]± 0,17	4,33[ab] ±0,14	4,54[b] ±0,13	4,21[a] ±0,11	0,000
Oil Holding Capacity (ml/g)	7,78± 0,06	7,70 ±0,09	7,75 ±0,13	7,87 ±0,07	0,104
Water Holding Capacity (ml/g)	7,575 ±0,05	7,54 ±0,08	7,59 ±0,18	7,52 ±0,25	0,937
Emulsifying Activity	0,55 ±0,19	0,45 ±0,16	0,54 ±0,14	0,35 ±0,09	0,271
Emulsion stability (min)	0,46[b] ±0,17	0,29[a] ±0,07	0,27[a] ±0,09	0,21[a] ±0,02	0,022

Solubility of sumbawa mare's milk powder: The results of the solubility parameter study showed that the addition of different dextrin levels significantly (P<0.01) affects the improvement of solubility in Sumbawa mare's milk powder. The data in Table 1 show that the solubility of Sumbawa mare's milk powder ranged from 68.70% to 86.54%. The highest solubility value was found in the 30% treatment, which resulted in 18% higher solubility. However, in general, the addition of dextrin can improve the solubility of the resulting milk powder. Furthermore, this study also found a significant correlation (P<0.05) between pH and solubility in Sumbawa Mare's Milk powder with various dextrin concentrations. The data show that lower pH is associated with poorer solubility compared to higher

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pH. These findings are consistent with the research by Corredig and Dalgleish, (1996), who reported that low pH in powdered milk can cause protein precipitation, which ultimately inhibits solubility. This phenomenon occurs because an acidic environment can cause structural changes to milk proteins, including denaturation and coagulation, which interfere with their ability to dissolve in water. Additionally, chemical reactions such as the Maillard reaction can produce insoluble compounds that worsen the rehydration process. On the other hand, powdered milk with a more neutral pH (higher pH) tends to have better solubility because it can maintain protein stability more effectively (Turk-Gul *et al*., 2023), This may explain why the 30% treatment had the highest solubility.

Protein plays a key role in determining the solubility of mare's milk powder. As explained by (Fox *et al*., 1998), mare's milk consists mainly of whey protein and casein, both of which contribute to good solubility. However, the solubility of protein in powdered milk can be influenced by drying conditions and the use of fillers during the powder manufacturing process. (Cais-Sokolińska *et al*., 2023) showed that the addition of dextrin to milk powder helps stabilize powder particles and increases rehydration efficiency. Rizqiati *et al*. (2021) found that dextrin concentrations between 5% and 15% had a significant effect (P<0.05) on the solubility of powdered milk, with the greatest effect seen at a concentration of 15%. Dextrin acts as a filler between powder particles, increasing the interaction between particles and water during the dissolution process. The addition of dextrin at different concentrations affects the particle size, water binding capacity, and rehydration potential of powdered milk.

Water content of sumbawa mare's milk powder: The results of the study indicate that the addition of different dextrin levels significantly (P<0.01) affects the water content of Sumbawa mare's milk powder. The highest water content was observed in the 15% dextrin treatment (5.25±0.17%), while the lowest water content (4.21±0.11%) was recorded in the treatment with 30% dextrin, which remains within the safe limits as defined by (Brouard *et al*., 2007). Overall, a decreasing trend in water content was observed with increasing dextrin levels. Post hoc analysis revealed no significant differences between the 20%, 25%, and 30% dextrin treatments, although the 30% dextrin treatment showed a significant difference compared to the 25% treatment. Conversely, the 15% dextrin treatment demonstrated significant differences compared to the other treatments.

The addition of dextrin influences the water content of milk powder by reducing overall water content, particularly at higher concentrations (>15%). This reduction occurs due to the hygroscopic properties of dextrin, which help decrease free water by binding it or reducing the availability of free water in the product. These findings are supported by further analysis, which showed significant differences between certain treatments, such as the 20%, 25%, and 30% dextrin concentrations. While the water content remained relatively constant at 4.33% to 4.54% in the 20%–25% treatments, this range might represent the maximum water-binding capacity of dextrin, explaining why a subsequent increase to 30% dextrin resulted in a further reduction in water content.

This phenomenon is consistent with the findings by Cais-Sokolińska *et al*. (2023), who reported that dextrin addition at these concentrations can reduce the water content of milk powder. However, at higher dextrin concentrations (>15%), the product's water content tends to increase due to the higher hygroscopic capacity of dextrin, as noted by Schuck *et al*. (2016). Despite the higher molecular weight dextrin's greater water-binding capacity, the observed decrease in water content at high dextrin levels may also be attributed to a dilution effect, where the concentration of milk decreases relative to the dextrin content. This is evident in the 25%–30% dextrin treatments, where the water content further decreased to 4.21% in the 30% dextrin treatment.

Water holding capacity of sumbawa mare's milk powder: The addition of dextrin to the powdered milk did not show a significant effect (P>0.05) on water holding capacity. The results of the study on the water holding capacity parameter in Table 1 summarize the physical and physicochemical properties of mare's milk powder. The addition of dextrin at levels of 15%, 20%, 25%, and 30% resulted in water holding capacities of 7.57±0.05 ml/g, 7.54±0.08 ml/g, 7.59±0.18 ml/g, and 7.52±0.25 ml/g, respectively. The sample with 15% dextrin addition exhibited the highest water holding capacity. This is due to the nature of dextrin as a polysaccharide, which has the ability to absorb and retain water. When dextrin is added to powdered milk, the dextrin molecules can absorb water molecules, thereby increasing the water holding capacity of the mixture. The interaction of dextrin with milk components facilitates the formation of a more stable matrix, which can hold more water, especially by interacting with proteins and fats in the powdered milk. In addition, the addition of dextrin can increase the viscosity of the powdered milk solution, which ultimately contributes to the increased bound water capacity. However, the samples have a relatively low range of water holding capacity (e.g., 0.20-0.35 g/g), which is still within safe limits for microbiological and chemical reactions (Faye and Konuspayeva, 2012).

The water solubility, oil holding capacity, and water holding capacity of powdered milk were evaluated to assess the physical quality of the product (Table 1). The solubili-

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ty value in water showed a significant increase along with increasing dextrin concentration (P<0.01). This may be caused by the higher density value of dextrin compared to milk fat and protein. In general, the property of water solubility is closely related to the composition and particle size of the powder. In accordance with the findings of Faye and Konuspayeva (2012), the solubility of mare's milk powder increases with increasing dextrin concentration up to 5%. A decrease in the fat content of powdered milk can also contribute to increased solubility, because milk fat has a lower density compared to other milk components (Wang *et al*., 2021). In addition, the solubility value of all powders decreased with the length of storage, which was possibly caused by an increase in water content in the powder (Nijdam and Langrish, 2006).

Oil holding capacity of sumbawa mare's milk powder: The addition of dextrin at different levels to the Sumbawa mare's milk powder did not show a significant effect (P>0.05) on the oil holding capacity. The study on the oil holding capacity parameter with the addition of dextrin at different concentrations (15%, 20%, 25%, and 30%) yielded values of 7.78±0.06 ml/g, 7.70±0.09 ml/g, 7.75±0.13 ml/g, and 7.87±0.07 ml/g, respectivel. Nevertheless, a relatively high trend was observed in the sample with the addition of 15% dextrin, which exhibited the highest oil holding capacity. This is due to the nature of dextrin as a polysaccharide, which has the ability to absorb and retain oil. When dextrin is added to powdered milk, the dextrin molecules can absorb oil molecules, thus increasing the oil holding capacity of the mixture. The interaction of dextrin with milk components allows the formation of a more stable matrix, which can hold more oil, especially through interaction with proteins and fats in the powdered milk. Additionally, the addition of dextrin can increase the viscosity of the powdered milk solution, which ultimately contributes to the increased oil binding capacity. However, the samples had a relatively low range of oil holding capacity (e.g., 0.20-0.35 g/g), which is still within safe limits for microbiological and chemical reactions (Faye and Konuspayeva, 2012). Huang *et al*. (2020), further added that the combination of vacuum drying and the addition of dextrin can increase oil absorption and stability of the final product. These findings are relevant for Sumbawa Mare's Milk powder, which is often used as a functional product in various applications. The study by (Xie *et al*., 2023) also showed that the use of dextrin in combination with vacuum drying increases the stability and oil holding capacity of powdered products through more effective control of humidity during the drying process. The interaction between dextrin and low temperature in vacuum drying helps maintain the physical structure of the particles, which contributes to the increase in OHC. This explains why no significant effect was found on the oil holding capacity at various dextrin concentrations in mare's milk powder.

Emulsifying activity of sumbawa mare's milk powder: The statistical analysis showed that there was no significant difference (P>0.05) in the emulsifying activity of Sumbawa mare's milk powder. The results of the emulsifying activity test of Sumbawa mare's milk powder with different dextrin levels, as shown in Table 1, revealed values of 0.55±0.19 at 15%, 0.45±0.16 at 20%, 0.54±0.14 at 25%, and 0.35±0.09 at 30% dextrin. This is in line with the results obtained for oil binding capacity, because emulsion activity and oil holding capacity have a close relationship. These two parameters are related to the ability of powdered milk to hold and distribute oil in its matrix. Therefore, if OHC did not show significant differences, the emulsion activity is also expected to not be significantly affected.

Emulsion activity and oil holding capacity are important factors in determining product stability. High emulsion activity is usually associated with increased oil holding capacity because the formation of a stable emulsion reduces the possibility of oil separation from the matrix. In a stable emulsion, the oil is evenly distributed in the water phase and bound by proteins and other emulsifying agents, which helps maintain the overall integrity of the product.

Despite this relationship, the results of this study show that overall the emulsion activity values are still within normal limits, as reported by (Wang *et al*., 2021). These values are consistent with the typical range for powdered milk, indicating that the dextrin concentrations used in this study did not have an adverse effect on emulsion stability. Emulsion stability is critical to ensuring the quality and functionality of milk powder, especially in products intended for rehydration or use in functional food applications. In conclusion, the lack of significant differences in emulsion activity and oil holding capacity supports the idea that dextrin concentrations within the tested range do not significantly alter the emulsion characteristics of mare's milk powder. These findings contribute to the understanding of how dextrin affects the physical properties of powdered milk and demonstrate that careful control of dextrin concentration is necessary to maintain desired product stability.

Emulsion stability of sumbawa mare's milk powder: The results of the study showed that the addition of dextrin at different levels, as presented in Table 1, resulted in varying values with a decreasing trend (P<0.05) in line with the increasing dextrin levels. The highest value was obtained at the 15% treatment with 0.46±0.17 min, while the lowest value was found at the 30% treatment with a value of 0.21±0.02 min. The decreasing trend observed with increasing dextrin levels in emulsion stability was influenced by several factors, including particle size, temperature, pH, as well as the type and concentration of emulsifier used. In this study, the stability of Sumbawa mare's milk powder emulsion primarily depended on the interaction

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between milk proteins, particularly whey protein, and the fats present in the milk. As explained by (Gagnaire *et al*., 2019) whey protein functions as a natural surfactant that stabilizes fat droplets by forming a protective layer around them, preventing coalescence and phase separation.

The addition of dextrin at low levels did not significantly reduce the stability of the emulsion, as shown in Table 1. Mare's milk contains more whey protein compared to cow's milk, which contributes to the formation of a more stable emulsion. The stability of powdered Sumbawa mare's milk emulsion is influenced by various factors, including protein composition, processing methods, and storage conditions. One of the key factors influencing emulsion stability is the protein composition of milk. The whey proteins in mare's milk, especially β-lactoglobulin and α-lactalbumin, have excellent emulsifying properties. These proteins form a layer around the fat droplets, preventing the droplets from merging or fusing, which can cause emulsion instability. Soltani *et al*. (2017) highlighted that the high whey protein content in mare's milk provides a better emulsion stabilization effect compared to casein, which is dominant in cow's milk. In addition, whey protein has a more flexible structure, allowing a more even distribution on the surface of the fat droplets, thereby increasing the stability of the emulsion. This makes mare's milk an excellent candidate for producing stable emulsions, especially in powder form, where physical and chemical interactions between proteins and fats are essential to maintain product integrity.

Thus, the results of this study confirm that the addition of dextrin at low levels does not have a negative impact on the stability of mare's milk powder emulsions. This can be attributed to the inherent emulsifying properties of the whey proteins present in milk. The combination of stable protein interactions and the presence of emulsifying agents such as dextrin helps to maintain a good distribution of the fat phase in the emulsion, thereby ensuring the stability of the powdered product during storage.

Microstructural Analysis

Fesem/Edx (field emission scanning electron microscope-energy dispersive x- ray spectroscopy): Qualitative analysis using FESEM images in this study showed different microstructural changes in Sumbawa Mare's Milk powder produced with varying dextrin concentrations (15%, 20%, 25%, and 30%). At a dextrin concentration of 15%, a fine granular microstructure with little aggregation was clearly visible (Figure 1a). In contrast, at a dextrin concentration of 20%, there was a more interconnected granular network compared to 15% dextrin (Figure 1b). Figure 1c shows that at a dextrin concentration of 25%, irregularly shaped aggregates dominate the microstructure of powdered Sumbawa mare's milk. Meanwhile, at a dextrin concentration of 30% (Figure 1d), more disordered aggregates dominate the microstructure of the powdered milk.

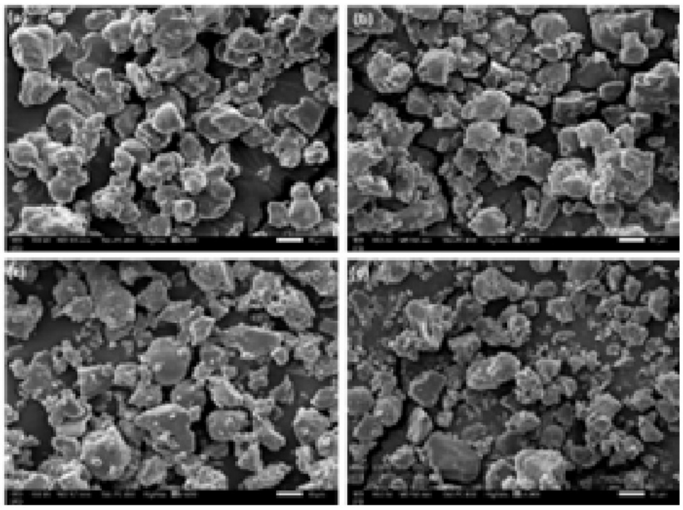

Figure 1: Field emission scanning electron micrograph of mare's milk powder particles: **a:** dextrin concentration 15%; **b:** 20% dextrin concentration; **c:** 25% dextrin concentration; **d:** 30% dextrin concentration.

Comparison of elemental analysis of mare's milk powder with different concentrations of dextrin shows that the carbon mass at the percentage of dextrin addition of 15%, 20%, 25%, and 30%, respectively, is 54.58±1.36, 57.30±2.00, 54.74±1.01, and 55.92±1.09 atom % (Table 1). Nitrogen mass was more (3.17±0.86 atom %) at 15% dextrin concentration which decreased at 20% (1.35±1.39 atom %) then a slight increase was observed at 25% (2.07±2.12 atom %) and 30% (2.51±2.99 atom %). On the other hand, the oxygen mass increased from 39.74 ± 0.83 atom % to 41.39 ± 1.53 atom % with an increase in concentration from 15% to 25% and decreased (39.88 ± 1.78 atom %) at 30% dextrin. The sodium mass did not change at 15% and 20%, while the sodium mass increased at 25% dextrin and decreased at 30% dextrin. Meanwhile, Magnesium mass decreased from 0.16 ± 0.11 atom % to 0.08 ± 0.05% with an increase in dextrin concentration from 15% to 25% and an increase in 30% dextrin. The mass of potassium was 1.13 ± 0.36 atom %, 0.33 ± 0.09 atom %, 0.51 ± 0.39 atom %, and 0.87 ± 0.23 atom %c at dextrin concentrations of 15%, 20% respectively , 25%, and 30% (Table 1). Similarly, the mass of calcium is 1.17±0.16 atom %, 0.81±0.49 atom %, 1.06±0.07 atom %, 0.64±0.10 atom % at 15% dextrin concentration respectively, 20%, 25%, and 30% (Table 2).

The results of this study provide important insights into the microstructural changes and variations in elemental composition in powdered Sumbawa mare's milk in response to different dextrin concentrations (Figure 2). These findings have significant implications for the quality and functionality of Sumbawa Mare's Milk powder. The observed microstructural changes indicate that dextrin concentration plays an important role in determining the physical properties of the powder. At a dextrin concentration of 15%, a fine granular microstructure with minimal aggregation was observed, indicating that the particles were well dispersed and unlikely to form large clusters. These characteristics can be beneficial for applications that require uniform mixing and dissolution (Marcu *et al.*, 2013).

Table 2: Comparison of elemental analysis mapping of mare's milk powder made from various concentrations of dextrin.

Elements (atom %)	**Dextrin Concentration**			
	15%	**20%**	**25%**	**30%**
C	54,58±1,36	57.30±2.00	54,74±1,01	55,92±1,09
N	3,17±0,86	1,35±1,39	2,07±2,12	2,51±2,99
O	39,74±0,83	40,01±1,36	41,39±1,53	39,88±1,78
Na	0,06±0,06	0,06±0,14	0,15±0,12	0,01±0,01
Mg	0,16±0,11	0,14±0,10	0,08±0,05	0,17±0,05
K	1,13±0,36	0,33±0,09	0,51±0,39	0,87±0,23
Ca	1,17±0,16	0,81±0,49	1,06±0,07	0,64±0,10

C: carbon; **N:** nitrogen; **O:** oxygen; **Na:** Sodium; **mg:** magnesium; **K:** Potassium; **Ca:** Calcium.

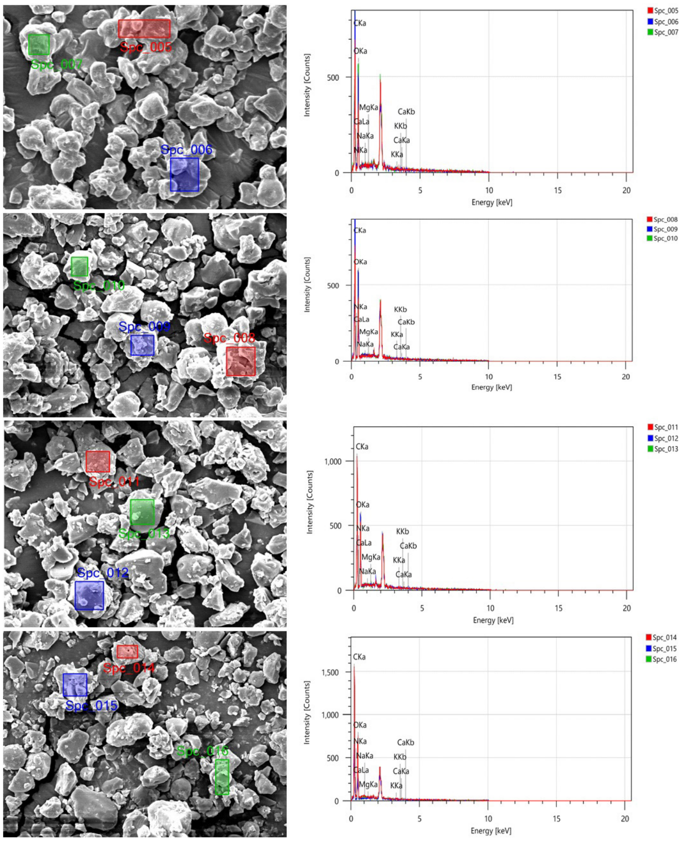

Figure 2: Effect of dextrin levels on the microstructure (fesem) of horse milk powder.

Increasing the dextrin concentration to 20% resulted in a more interconnected network of granules, indicating that dextrin has a binding effect and promotes interactions between particles. This more connected granular network can influence the flowability of the powder as well as its suspension ability in the liquid product. At dextrin concentrations of 25% and 30%, the microstructure showed the formation of irregularly shaped aggregates, which were more dominant at a concentration of 30%. These aggregates can affect the texture, solubility, and dispersion properties of the powder, which is relevant for applications that require a particular texture or mouthfeel.

Changes in elemental composition with variations in dextrin concentration indicate a complex interaction between dextrin and components of Sumbawa mare's milk powder (Rizqiati *et al.*, 2021). The increase in carbon content with increasing dextrin concentration indicates that dextrin contributes to the carbon content in the powder, which may be due to the carbon-rich nature of dextrin. Nitrogen content, on the other hand, showed fluctuations with variations in dextrin concentration. The peak of nitrogen content at 15% dextrin concentration was followed by a decrease at 20%, and a slight increase at 25% and 30%, indicating the sensitivity of nitrogen content to changes in dextrin concentration. This variation is likely related to the capacity of dextrin to bind nitrogen-containing compounds in powdered milk.

The increase in oxygen content at 25% dextrin concentration, followed by a decrease at 30% concentration, reflects changes in the binding or complexation of oxygen-containing groups in dextrin, which may affect the oxidative stability of the powder. Variations in sodium and magnesium content indicate that dextrin affects the solubility or retention of these minerals in the powder, which may impact the nutritional profile of the final product. Furthermore, fluctuations in potassium and calcium content with dextrin concentration can affect mineral fortification in products containing Sumbawa Mare's Milk powder.

These findings have significant practical implications for the formulation and application of Sumbawa Mare's Milk powder in various food and beverage products. Based on the desired characteristics of the final product—such as texture, solubility, and mineral content—the dextrin concentration can be optimized. For example, lower concentrations of dextrin may be preferred for applications requiring even dispersion and minimal aggregation, while higher concentrations may be applied to products where higher aggregation is desired.

CONCLUSIONS AND RECOMMENDATIONS

The research results show that the addition of dextrin to powdered Sumbawa Mare's Milk can improve the phys-

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ical and functional properties of the product, including water holding capacity, solubility and stability. The addition of dextrin at a concentration of 15% was effective in preventing the formation of lipid bridges and reducing the free fat content, which ultimately minimized agglomeration and increased reconstitution properties. A dextrin concentration of 15% proved to be the optimal condition that maintains a balance between reducing the free fat content and maintaining the structural integrity of powdered milk. Scanning electron microscopy (FESEM) analysis shows that variations in dextrin concentration in powdered Sumbawa Mare's Milk significantly influence the microstructure and elemental composition of powdered milk and influence the quality and functionality of the final product. The addition of dextrin at a concentration of 15% produces a finer and more dispersed microstructure, ideal for applications requiring mixing and dissolving. Meanwhile, higher dextrin concentrations (20%, 25%, and 30%) cause structural changes to become more aggregated, with the highest concentrations showing disordered aggregates, which affects the texture and solubility properties. Thus, the microstructure contributes to the improvement better reconstitution properties and flowability.

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NOVELTY STATEMENT

This study presents a novel investigation into the effects of varying dextrin levels on the physicochemical properties and microstructure of Sumbawa mare's milk powder, using the VFOD method. Results indicate that the addition of 15% dextrin yields the highest quality in both physicochemical properties and microstructure. However, even with a 25% dextrin addition, the quality remains acceptable. Phase imaging further supports these findings, revealing that up to 25% dextrin results in a relatively uniform structure with no significant differences in carbon content. Notably, the 15% dextrin treatment consistently exhibited superior concentrations of Ca, K, Mg, and N. These findings offer valuable insights for optimizing the processing of liquid Sumbawa mare's milkinto powder, enhancing both storage efficiency and product quality.

AUTHOR'S CONTRIBUTIONS

Yunita Sari and Pramudya Andiana executed the experiment, conducted laboratory analysis, analyzed the data, and drafted the original manuscript. Arif Hendra Utama conducted laboratory analysis. Arif Irawan analyzed the data and revised the manuscript. Riska Faradila, Abdul Manab and Lilik Eka Radiati designed and supervised the study and drafted the manuscript. All authors read and agreed on the final manuscript.

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Conflict of Interest

The authors declare no conflict of interest with any organization or third party regarding the material discussed in this research.

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