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Effects of maltodextrin in freeze drying on the physical and functional properties of different type of milk powder

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ABSTRACT

This study examines the impact of maltodextrin concentration (0%-20%) on the physical and functional properties of freeze-dried cow and mare milk powder. Maltodextrin, a common additive in milk powder production, can significantly affects the physical properties of the powder by improving solubility, texture, and prevents clumping. The research aims to evaluates the effects of maltodextrin concentrations on freeze-dried cow and mare milk powder. Samples were prepared by homogenizing fresh milk and adding maltodextrin at various concentrations. The milk was then freeze-dried, and the properties of the resulting milk powder were analyzed. Results show that maltodextrin addition reduced moisture content in both cow and mare milk powders. Bulk and tapped density increased with higher maltodextrin concentrations. The addition of maltodextrin also improved flowability, as indicated by lower Carr Index and Hausner ratio values. Morphological analysis revealed a smoother texture and uniform particle size in freeze-dried milk powder with higher maltodextrin levels. Solubility and foaming capacity also improved, with cow milk generally exhibiting better solubility compared to mare milk. In conclusion, maltodextrin concentration enhances the physical and functional properties of freeze-dried cow and mare milk powders.

PRACTICAL APPLICATION

The findings contribute valuable insights for optimizing milk powder production processes and enhancing product quality.

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1. Introduction

Different types of milk have different compositions of protein, fat, lactose, and mineral content. In general, mare milk has lower fat and casein content than cow and camel milk (Benmeziane–Derradji, 2021; El-Agamy, 2007; Konuspayeva et al., 2009; Nayak et al., 2020). These will affect the functional properties of milk powder, such as solubility, emulsifying properties, and foaming properties. The composition of the milk from different animals could also vary depending on factors such as processing conditions, breed, and diet (Deshwal et al., 2020; Hazeleger & Beumer, 2016; Zouari et al., 2020a; 2020b).

Milk powder can be produced via several methods, such as spray drying and freeze drying. Spray drying involves atomizing the liquid product into fine droplets and drying them rapidly via hot air. This process is suitable for heat-sensitive products and able to produce powdered forms with good solubility. Spray-dried products have a longer shelf life, are easy to handle, and can be used in various applications. Freeze drying, also known as lyophilization, involves freezing the product and then removing the water through sublimation, resulting in the formation of a porous structure. This process helps to preserve the product's structure, flavor, and nutritional content especially heat-sensitive materials (Ibrahim & Khalifa, 2015). Freeze-dried products also have a long

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shelf life due to the low moisture content and water activity and can be easily rehydrated due to the minimal drying shrinkage. Freeze-drying yields lightweight products with high retention of antioxidants, nutrients, and bioactive compounds (Cais-Sokolińska et al., 2023; Harizi et al., 2023).

Despite its benefit, freeze drying process is quite costly and time consuming, limiting its application in the industry in certain products only such as probiotics and starter culture preservation process (Bhushani & Anandharamakrishnan, 2017). Several research had been done on freeze drying of several types of milk and milk derived products, focusing on certain qualities of freeze-dried powdered milk (Cais-Sokolińska et al., 2023; Deshwal et al., 2020; Doneva et al., 2021; Shingisov & Alibekov, 2017; Tastemirova et al., 2020; 2022; Zhang et al., 2022).

In milk powder production, the physical quality and nutritional properties of the powder are affected by the drying methods. According to Deshwal et al. (2020), spray drying and freeze drying have significant effects on the composition and color values of camel milk powder with freeze drying resulting in higher retention of certain components and different color characteristics compared to spray drying. The spray dried and freeze-dried powder also exhibit different physical properties such as bulk density, flowability, wettability, dispersibility, and solubility. Freeze-dried milk powder has better flowability and higher wettability, dispersibility, reconstitution properties, and foaming capacity, while spray dried milk powder tends to have higher solubility. The freeze-dried process also maintains the physical and chemical stability of the milk powder more effectively during storage than spray drying (Cais-Sokolińska et al., 2023; Deshwal et al., 2020; Harizi et al., 2023; Ho et al., 2019; Ibrahim & Khalifa, 2015).

Maltodextrin is often used in the manufacturing of milk powder, particularly in freeze drying, and has a noticeable impact on its physical qualities. These include increased solubility because maltodextrin develops a protective coating around milk particles with good freezing stability, keeping them from clumping and increasing rehydration (Fioramonti et al., 2015; Xiao et al., 2022). It also contributes to a smoother and creamier feeling in reconstituted milk (Loi et al., 2020; Xiao et al., 2022). As a bulking agent, it increases powder volume while maintaining nutritious value, making the product more economically viable. Maltodextrin acts as an anti-caking agent, preventing particle aggregation and maintaining the powder's free-flowing properties. It affects crystallisation during freeze drying, generating an amorphous matrix with milk solids to

manage the crystalline structure and ensure optimal product quality (Du et al., 2021). Furthermore, maltodextrin stabilises lipids, preventing oxidation and rancidity during storage.

Although both spray drying and freeze drying have their advantages and disadvantages, freeze drying generally offers more advantages in product quality. This study aims to investigate the effect of the addition of different maltodextrin concentrations (0%–20%) on the physical properties such as moisture content, density, flow properties, colour attributes and morphology and functional properties such as foaming capacity on freeze dried cow and mare milk powder.

2. Materials and methods

2.1. Preparation of sample

Fresh cow milk and mare's milk were purchased from the supermarket. The milk was placed in the beaker and each milk sample was homogenized by using a homogenizer (DAIHAN-brand Homogenizer with Direct Controller, 'HG-15A', Switzerland) at speed 5 for 3 minutes. Then the milk sample was added with different concentration of maltodextrin at 10% and 20% (w/w), and the samples were homogenized for 2 minutes (Baldelli et al., 2022).

2.2. Freeze drying process

The freeze-drying process was carried out at -112°C using the Bench-top freeze dryer (Coolsafe 110-4, Labogene APS Industries, Denmark). Maltodextrin was added at different concentration (10%–20%) of weight-to-weight ratio and the mixture was homogenized. Prior to the freeze-drying process, 300 ml of fresh cow's milk and mare's milk sample were placed in the container, with a thickness around 4 mm then frozen for 24 hours at -30°C in the freezer. Afterward, the frozen samples were placed in the freeze dried for 72 hours. Then the powder was collected and grinded using a food grinder (Model-1000A, Lejieyin, China) to get the powder after it been freeze dried. The powder produced then was kept in seal packaging material until used for analysis.

2.3. Moisture content analysis

Moisture content was determined gravimetrically by using the standard method of AOAC (2000). About 2 g of samples were dried at 105°C and kept in desiccators before being weighed until a constant weight was achieved.

2.4. Physical properties analysis

2.4.1. Bulk density and tapped density analysis

The method used to determine the bulk density and tapped density followed the procedure recommended by Abreha et al. (2021). This involved weighing 5g of milk powder and transferring it into a 25mL measuring cylinder. The initial weight and volume of the sample were recorded. The aerated bulk density was calculated by dividing the initial mass of the powder by the volume taken up by the cylinder. The powder was then tapped continuously (250 times) on the surface by hand until no further change or a steady level was obtained, and the weight and volume were recorded. Finally, both densities (g/mL) were calculated using Equation (1)

$$\text{Aerated bulk density} = \frac{\text{weight of sample (g)}}{\text{volume of sample occupied the space (ml)}} \quad (1)$$

$$\text{Tapped density} = \frac{\text{weight of sample (g)}}{\text{volume of sample after tapping (ml)}} \quad (2)$$

2.4.2. Flowability analysis

The powder flowability can be described in terms of Carr Index (CI) and Hausner ratio (HR) where smaller CI and HR indicates better flowability. It can be calculated as follows (Goyal et al., 2015)

$$\text{Carr Index (CI)} = \frac{\rho_t - \rho_b}{\rho_t} \quad (3)$$

$$\text{Hausner ratio (HR)} = \frac{\rho_t}{\rho_b} \quad (4)$$

where ρ_t powder tapped density and ρ_b is powder bulk density.

2.4.3. Colour analysis

The colour of the milk powder samples was measured using a colorimeter (Precise Colour Reader, WR-18, ShenZhen Wave Optoelectronics Technology Co, Ltd.) to determine the CIE colour parameters (L^* , a^* , and b^*). The L^* coordinate in this system represents lightness, ranging from 0 (black) to 100 (white). The a^* coordinate indicates red (+) or green (-), while the b^* coordinate represents yellow (+) or blue (-). The total colour differences (ΔE) were calculated using Equation (5)

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (5)$$

2.4.4. Morphology analysis

The samples underwent SEM analysis using a JSM - IT 100 InTouch Scope Scanning Electron Microscope (JEOL Ltd, Singapore). They were affixed to double-sided carbon tape and stored in a desiccator with silica gel for a minimum of 24 hours. The samples were coated with gold and the accelerating voltage used was 10kV.

2.4.5. Solubility analysis

The solubility of milk powders was determined using the method described by Haque et al. (2012) and Meena et al. (2017) with slight modifications. A 50ml, 10% (w/v) solution of milk powders was continuously stirred at 500rpm at $25 \pm 1^\circ\text{C}$ for 15 minutes (bulk solution), then transferred to a 50ml centrifuge tube and centrifuged at $2000 \times g$ for 10 minutes. Subsequently, 2ml of the homogenous solution was transferred to an aluminum dish and weighed, then the solution was centrifuged again under the same conditions and another 2ml of the solution was transferred to a second aluminum dish and weighed. Both aluminum dishes were then placed on a steam bath until apparently dry, followed by placement in the oven for 90 minutes at 100°C . The solubility of the powders was calculated using the following equation:

$$\text{Solubility (\% by weight)} = \frac{A_1 \times B_2}{A_2 \times B_1} \quad (6)$$

where

A_1 is the mass of the bulk liquid collected immediately after the removal of fat

A_2 is the mass of the supernatant liquid

B_1 is mass of total solids of bulk liquid solution

B_2 is the mass of total solids of supernatant solution.

2.5. Functional properties analysis

2.5.1. Foaming capacity analysis

The foaming properties were determined by adapting the method from Meena et al. (2017). This involved diluting 2g of milk powder samples with 50mL of distilled water at room temperature and whipped for 5 minutes. Subsequently, the volume of the produced foam in the beaker was transferred to a measuring cylinder and measured, and the increase in foam volume was expressed as percentage of foam capacity.

3. Results and discussion

3.1. Effects of maltodextrin concentration on the physical properties of freeze-dried milk powder

In order to assess the effects of maltodextrin on the quality of the products, different concentration of maltodextrin was added. The samples were denoted as CM0, CM10, and CM20 which indicate cow milk with 0%, 10%, and 20% of maltodextrin, respectively. Similarly, mare milk powder samples were denoted as MM0, MM10, and MM20.

3.1.1. Effects on moisture content

Powdered milk is commonly found in the dairy industry due to ease of packaging and transport, and an extended shelf life. A high-quality powder should exhibit low moisture content and water activity. The physical properties of different freeze-dried powders, such as moisture content, density, and flow characteristics, are detailed in Table 1. Generally, mare milk contains higher moisture, ranging from $4.35 \pm 0.04\%$ to $8.14 \pm 0.09\%$, compared to cow milk powder, which falls within the range of $2.62 \pm 0.26\%$ to $3.24 \pm 0.04\%$. The addition of maltodextrin led to a reduction in moisture content in both types of milk powder. While cow milk experienced a 19% change, mare milk powder exhibited a more substantial 40% reduction of moisture content. This could be attributed to the higher moisture content in mare milk (Holmes et al., 1947; Musaev et al., 2021). However, upon adding 20% maltodextrin, the final moisture content in both CM20 and MM20 were almost similar. This shows the effectiveness of incorporating drying agents like

maltodextrin in the freeze-drying process. The introduction of maltodextrin is anticipated to increase solid content, resulting in lower moisture content. Similar findings have been documented in previous research studies (Caliskan & Dirim, 2016; Estupiñan-Amaya et al., 2020).

3.1.2. Effects on bulk density and tapped density

The density (bulk and tapped) of mare milk powder is slightly less than in cow milk powder in general, indicating that the freeze-dried mare milk powder is quite light and low-packed matrix. Addition of maltodextrin resulted in higher density as seen in Table 1 where the bulk density and tapped density for CM20 and MM20 is $0.6309 \pm 0.008 \text{ g/cm}^3$, $0.7319 \pm 0.001 \text{ g/cm}^3$, $0.5386 \pm 0.001 \text{ g/cm}^3$, and $0.6024 \pm 0.0005 \text{ g/cm}^3$, respectively. Increasing maltodextrin corresponds to an increase in bulk density and tapped density for cow milk powder as can be seen in CM10 and CM20. The density is increased by higher dry matter of feed. Moisture content affects the density of the powder (Goula & Adamopoulos, 2008) and in general, higher moisture content resulted in lower density. As higher concentration of maltodextrin was added, the dry matter of the feed is also increased therefore increasing the density. Similar results are seen in Goula and Adamopoulos (2008), Caliskan and Dirim (2016), and Cais-Sokolińska et al. (2023). In contrast, the effect of maltodextrin on the tapped density of mare milk powders (MM) was less pronounced but slightly decreased. This could be due to the higher initial moisture content of mare milk, which may lead to less efficient interaction between

Table 1. Effects of maltodextrin concentration on moisture content, density and flowability (Carr Index and Hausner ratio) of freeze-dried milk powder.

Sample	Maltodextrin composition (%)	Moisture content (%)	Bulk density (g/cm^3)	Tapped density (g/cm^3)	Carr Index (%)	Hausner ratio
CM0	0	3.24 ± 0.04^a	0.4713 ± 0.01^a	0.5806 ± 0.01^a	18.85 ± 1.205^a	1.23 ± 0.019^a
CM10	10	3.02 ± 0.08^b	0.5898 ± 0.01^b	0.7309 ± 0.01^b	19.28 ± 2.807^b	1.24 ± 0.043^a
CM20	20	2.62 ± 0.26^c	0.6309 ± 0.01^c	0.7319 ± 0.00^c	13.80 ± 1.178^c	1.16 ± 0.016^a
MM0	0	8.14 ± 0.09^d	0.5248 ± 0.01^d	0.6674 ± 0.01^d	21.37 ± 0.221^d	1.27 ± 0.004^a
MM10	10	8.08 ± 0.09^e	0.5230 ± 0.01^e	0.6003 ± 0.00^e	12.88 ± 0.541^e	1.15 ± 0.007^a
MM20	20	4.53 ± 0.04^f	0.5386 ± 0.00^f	0.6024 ± 0.00^f	10.58 ± 0.153^f	1.12 ± 0.002^a

Values with different superscript in the column represent statistical data significance ($P < 0.05$).

Table 2. Effects of maltodextrin concentration on colour attributes of freeze-dried milk powder.

Sample	Maltodextrin Composition (%)	L*	a*	b*	Delta E
CM0	0	79.52 ± 0.71	0.38 ± 0.07	5.68 ± 0.22	–
CM10	10	77.74 ± 0.16	0.63 ± 0.01	0.23 ± 0.07	5.63 ± 0.06^a
CM20	20	79.90 ± 0.22	0.66 ± 0.01	2.22 ± 0.06	4.43 ± 0.07^b
MM0	0	74.83 ± 0.52	-0.74 ± 0.09	3.45 ± 0.09	–
MM10	10	87.68 ± 0.16	-0.35 ± 0.21	8.51 ± 0.12	11.42 ± 0.10^c
MM20	20	88.81 ± 0.49	0.09 ± 0.01	5.27 ± 0.17	14.64 ± 0.50^d

Where *L represents lightness, a* represents green–red opponents, and *b represents blue–yellow opponents. Values with different superscript in the column represent statistical data significance ($P < 0.05$).

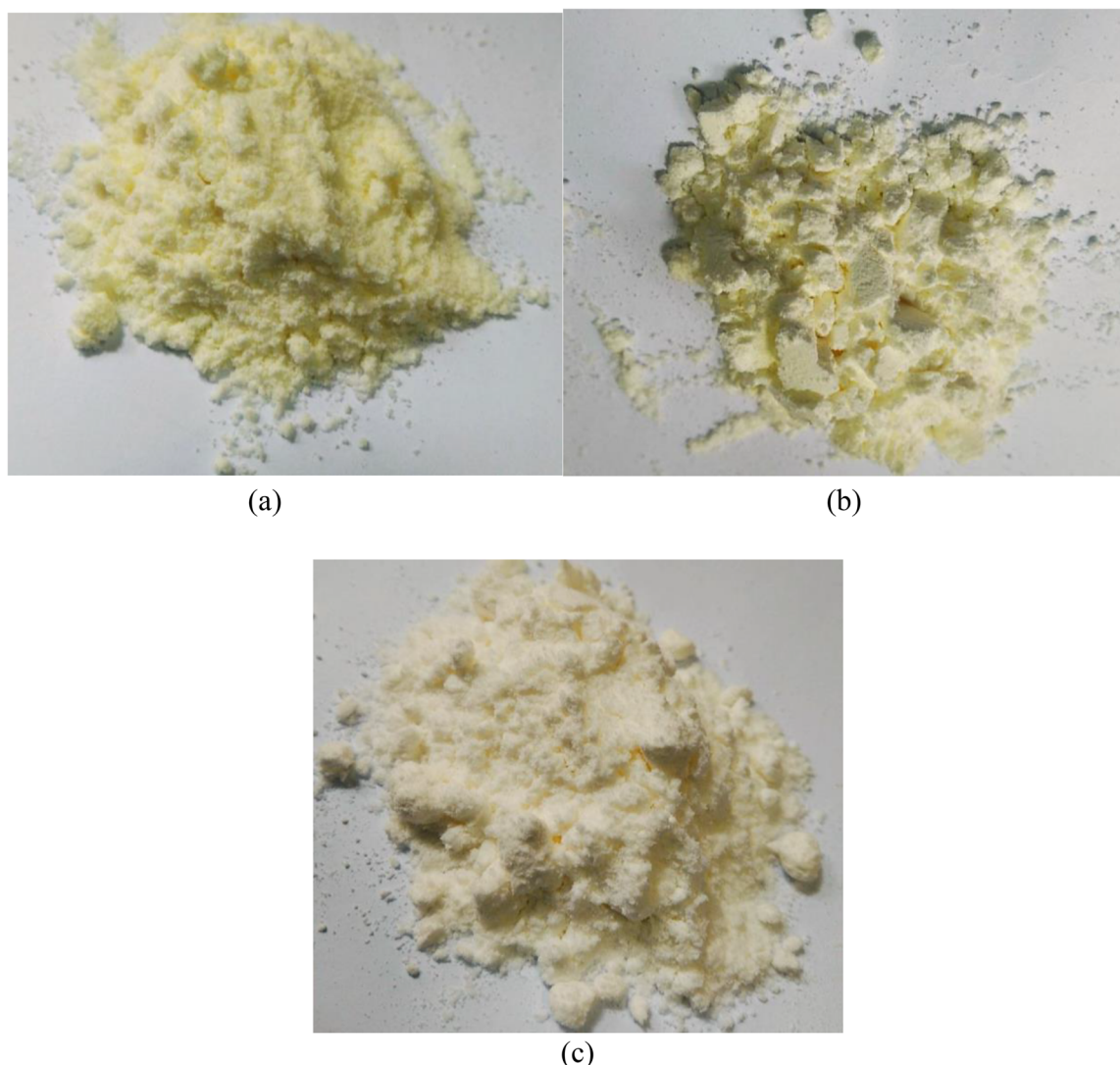


Figure 1. Freeze dried cow milk powder at different maltodextrin concentration (a) CM0, (b) CM10, and (c) CM20.

maltodextrin particles and the milk solids. In general, mare milk also contains higher protein and lower fat which may lead to more porous structure resulting in lower tapped density (Potočník et al., 2011).

3.1.3. Effects of different concentration of maltodextrin on flowability

The powder's flowability is a crucial quality factor, as it affects the storage, transportation, and packaging processes. Powder flowability and cohesion can be assessed using the Carr Index and Hausner ratio. The Carr Index is a measure of powder compressibility and a value of Carr Index exceeding 25 signifies poor flowability, while a value below 15 indicates good flowability (Goyal et al., 2015). By comparing freeze-dried mare milk powder with maltodextrin to cow milk powder in Table 1, the former demonstrates superior flowability due to a lower Carr Index (CI). For instance,

the CI for MM10 and MM20 is between $12.88 \pm 0.541\%$ and $10.58 \pm 0.153\%$, respectively. In contrast, the CI for CM10 and CM20 is higher at $19.28 \pm 2.807\%$ and $13.80 \pm 1.178\%$, respectively. Notably, CM0, exhibits a CI of $21.37 \pm 0.221\%$, proving the significance of maltodextrin in the freeze-drying process.

The Hausner Ratio is another indicator of powder flow, with a value below 1.12 indicating good to excellent flowability, above 1.25 suggesting poor flowability, and values in between indicating fair to passable flowability. In both types of milk, the freeze-dried milk powder with a higher concentration of maltodextrin exhibited improved flowability, reflected in the smallest HR of 1.16 ± 0.016 and 1.12 ± 0.002 in CM20 and MM20, respectively, compared to 1.23 ± 0.019 in CM0 and 1.27 ± 0.004 in MM0. The addition of maltodextrin caused a reduction in cohesiveness, resulting in better flow behavior. It also contributed to lower moisture content and acts as

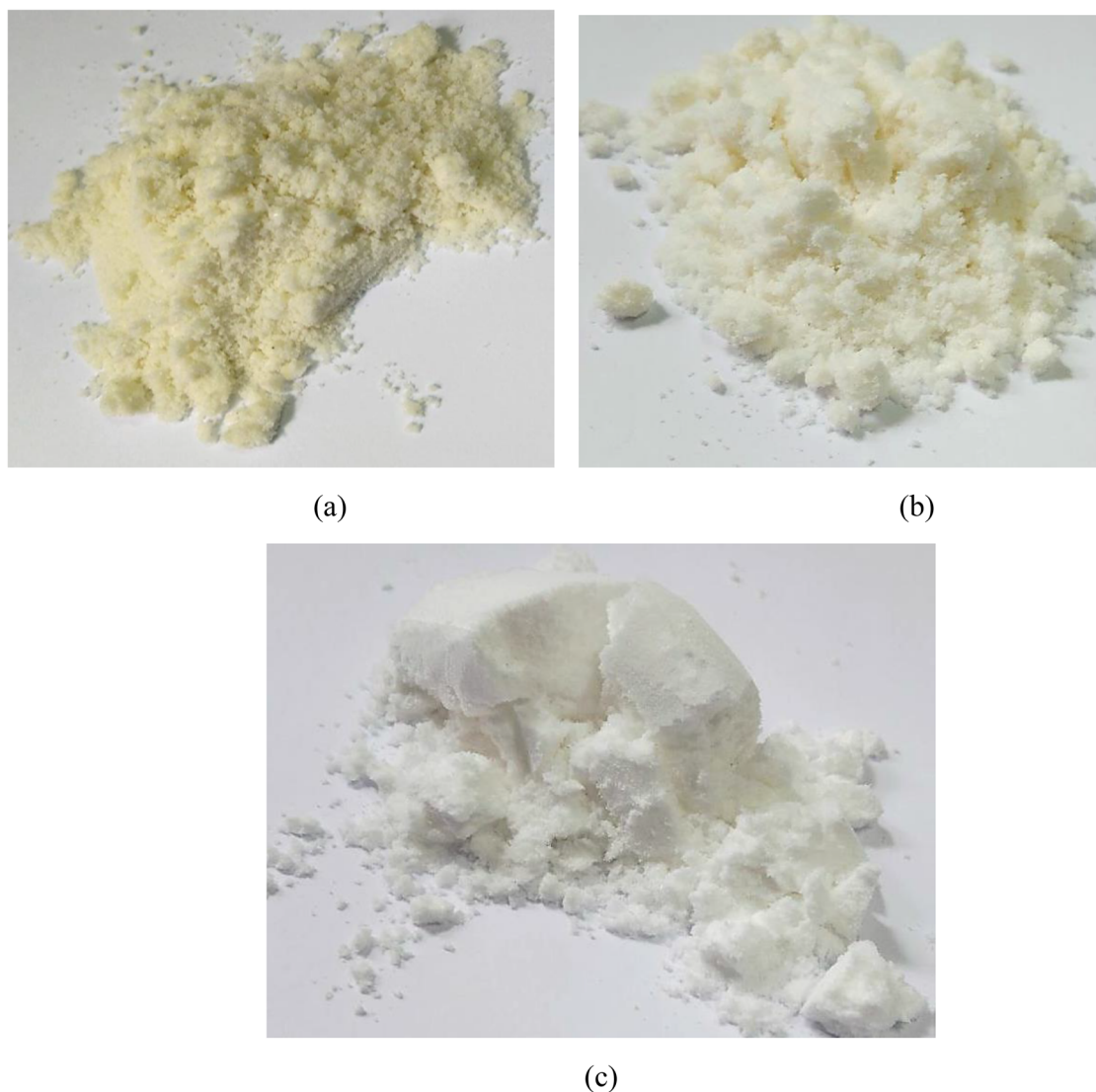


Figure 2. Freeze dried mare milk powder at different maltodextrin concentration (a) MM0, (b) MM10, and (c) MM20.

anti-caking agent to prevent formation of lumps, resulting in improving the flow properties (Caliskan & Dirim, 2016; Deshwal et al., 2020).

3.1.4. Effects of different concentration of maltodextrin on colour

The CIELAB color system presented reading in terms of lightness (L^*) and color (a^* and b^*). The chromatic a^* axis in the three-dimensional model runs from green ($-a^*$) to red ($+a^*$), whereas the chromatic b^* axis runs from blue ($-b^*$) to yellow ($+b^*$). L^* represents the lightness dimension, which spans from 0 (complete black) to 100 (complete white). The ΔE^* is the total colour change in the product without and with addition of maltodextrin. The colour of cow milk is slightly yellowish while mare's milk is paler white colour. Adding maltodextrin resulted in lighter colour for both types of powder, due

to the nature colour of maltodextrin, which is white (Table 2). Figures 1 and 2 show the photo of the powder. The freeze-dried cow milk powder has a yellowish colour as compared to mare's milk powder which is ore white or pale yellow. The whiteness of milk powder is due to light scattering by casein micelles. Similar results were observed in Caliskan and Dirim (2016) and Deshwal et al. (2020). Freeze-dried cow milk powder has been found to have lower L^* values ranging from 77.74 ± 0.16 to 79.90 ± 0.22 , compared to mare milk powder with L^* values in between 74.83 ± 0.52 and 88.81 ± 0.49 .

3.1.5. Effects of different concentration of maltodextrin on microstructure

The typical morphology of freeze-dried powder exhibits an irregular shape (Estupiñan-Amaya et al., 2020). The powders are shown in Figures 1 and 2. Microscopic analysis reveals that freeze-dried milk is composed of

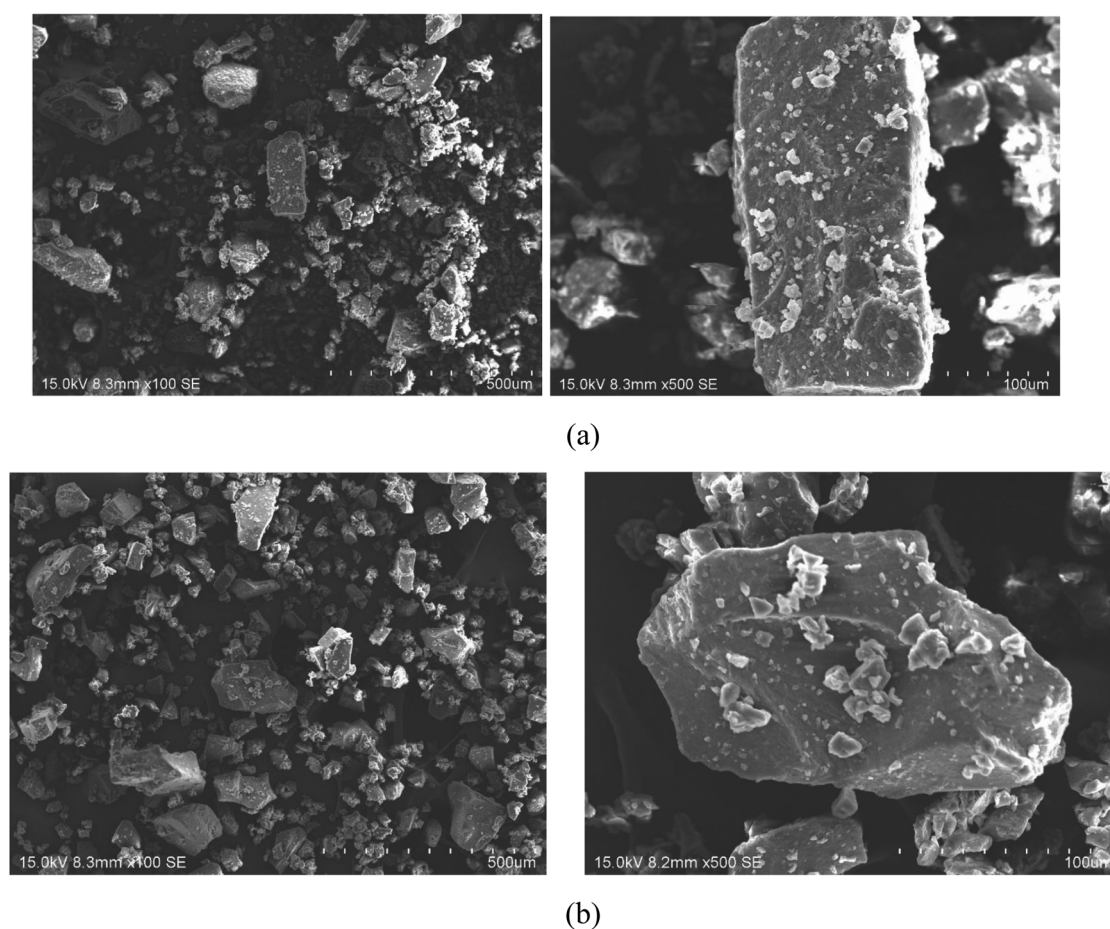


Figure 3. Scanning electron microscopy (SEM) images of freeze-dried cow milk powder at different maltodextrin concentration (a) CM10 and (b) CM20.

irregularly shaped porous particles as depicted in Figures 3 and 4. Both samples exhibit rough surfaces, particularly noticeable in mare milk powder. Maltodextrin plays a crucial role in modifying the particle morphology of milk powder during freeze-drying. Its interaction with milk proteins and fats forms a complex network, preventing particle agglomeration. The addition of maltodextrin leads to freeze-dried milk powder with a uniform particle size and a smoother texture. Cow milk powder, as seen in Figure 3 for CM10 and CM20, display a more uniform morphology compared to MM10 and MM20. This observation aligns with other findings by Hazeleger and Beumer (2016), Zouari et al. (2020a), Zouari et al. (2020b), and Deshwal et al. (2020).

3.1.6. Effects of different concentration of maltodextrin on solubility

Table 3 illustrates the solubility of freeze-dried milk powder at various maltodextrin concentrations. Generally, freeze-dried cow milk powder exhibits slightly better solubility than freeze-dried mare milk. A higher solubility percentage implies that a substantial amount

of a substance can dissolve in each solvent under specific conditions. The addition of maltodextrin increased solubility in mare milk from $88.70 \pm 1.55\%$ without maltodextrin to $94.16 \pm 2.74\%$ with 20% of maltodextrin. A similar trend is observed in freeze-dried cow milk powder as more maltodextrin is added, with solubility increasing from $88.39 \pm 1.07\%$ without maltodextrin to $97.07 \pm 1.23\%$ with maltodextrin. This could be attributed to maltodextrin's affinity for water, leading to a higher water dissolution rate (Caliskan & Dirim, 2016).

3.2. Effects of maltodextrin concentration on foaming capacity

Foaming capacity refers to the ability of a powder to form stable foam when whipped or agitated. The foaming capacity increased with the addition of maltodextrin from $59.72 \pm 1.51\%$ (CM0) and $51.70 \pm 2.40\%$ in (MM0) without maltodextrin to 62.92 ± 1.75 (CM20) and 54.47 ± 1.69 (MM20) with 20% of maltodextrin. Maltodextrin forms a protective layer around air bubbles in the foam, preventing coalescence and collapse.

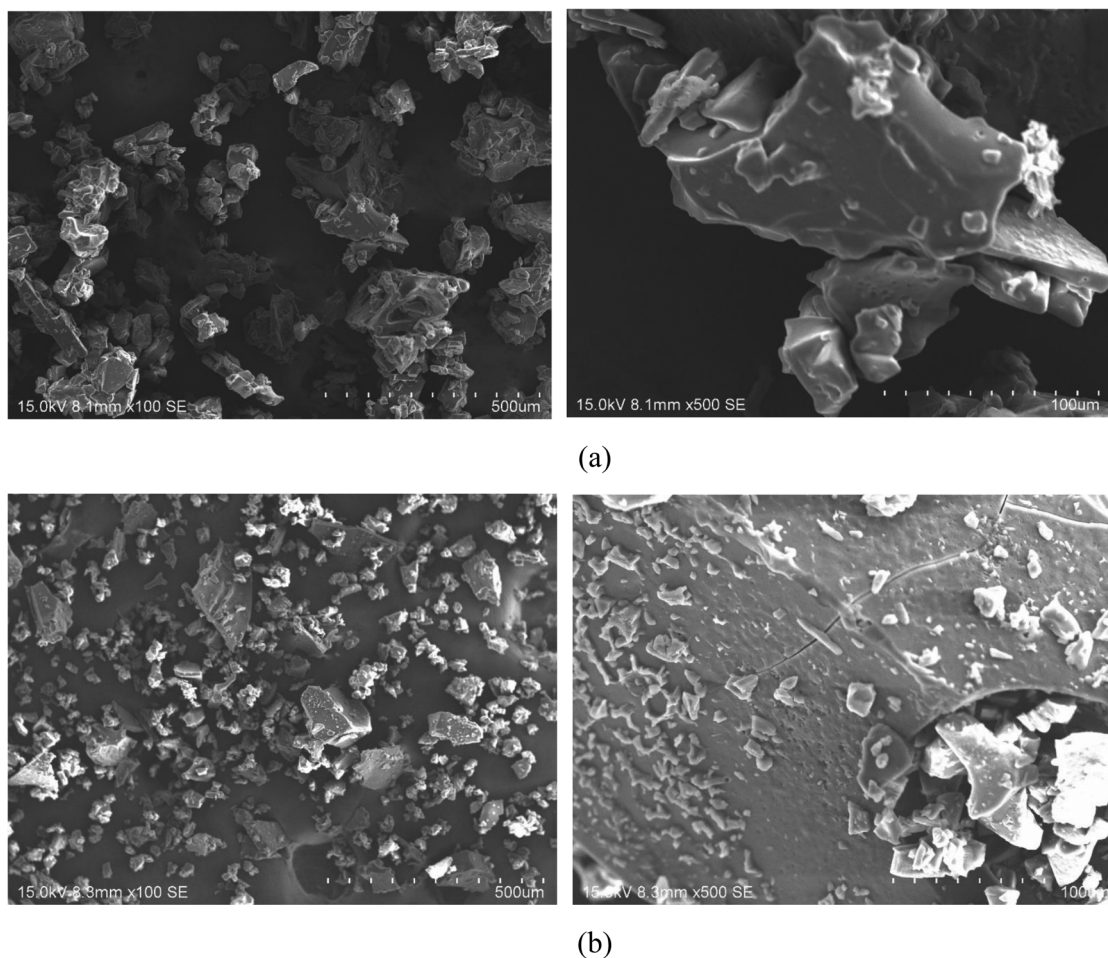


Figure 4. Scanning electron microscopy (SEM) images of freeze-dried mare milk powder at different maltodextrin concentration (a) MM10 and (b) MM20.

Table 3. Effects of maltodextrin concentration on solubility and foaming capacity (of freeze-dried milk powder).

Sample	Maltodextrin composition (%)	Solubility (%)	Foaming capacity (%)
CM0	0	88.39 ± 1.07 ^a	59.72 ± 1.51 ^a
CM10	10	92.70 ± 0.61 ^b	65.72 ± 0.89 ^b
CM20	20	97.07 ± 1.23 ^c	62.92 ± 1.75 ^c
MM0	0	88.7 ± 1.55 ^d	51.70 ± 2.40 ^d
MM10	10	92.40 ± 2.34 ^e	50.10 ± 1.22 ^e
MM20	20	94.16 ± 2.73 ^f	54.47 ± 1.69 ^f

Values with different superscript in the column represent statistical data significance ($P < 0.05$).

This enhanced stability can be beneficial in applications where long-lasting foam is desired. The porous structure of freeze-dried powder allows for better air entrapment and foam formation (Deshwal et al., 2020; Ho et al., 2019; Ibrahim & Khalifa, 2015).

4. Conclusion

This study explores the influence of maltodextrin concentration (0–20%) on the physical and functional attributes of freeze-dried cow and mare milk powder.

In general, the addition of maltodextrin reduced moisture content, increased bulk density, and improved flowability of the cow and mare milk powder, even though the response could be more prominent in cow milk. Maltodextrin also refines the powders' morphology, and boosts solubility and foaming capacity. These findings indicate that while maltodextrin generally improves properties, it may have a more complex effect on mare milk powder and could be investigated further.

Authors' contributions

The main conceptualization and design study were done by Farah Saleena Taip and Ravshanbek Sultanbekovich Alibekov. The experiments and analysis of data were done by Farah Saleena Taip, Aigerim Zhumagaliyeva Aitbayeva and Alifdalino Sulaiman. The manuscript are written, reviewed and edited by Farah Saleena Taip, Barna Makhamatovna Khamitova, Siti Mazlina Mustapa Kamal, Alifdalino Sulaiman and Abdugani Mutalovich Azimov. The project management and funding is monitored and acquired by Ravshanbek Sultanbekovich Alibekov. All

authors have read and agreed to the published version of the manuscript.

Disclosure statement

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Data availability statement

The data that support the findings of this study are available from the corresponding author, [FST] upon reasonable request.

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