Review

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Posted Date: 8 April 2024

doi: 10.20944/preprints202404.0559.v1

Keywords: Camel Milk; freeze-drying; powder; spray drying; Reduction of process duration

doi:10.20944/preprints202404.0559.v1

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Advancements in CM Drying Technology: A Comprehensive Review of Methods, Chemical Composition, and Nutritional Preservation

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Abstract: With the increasing interest in CM as a potential source of nutrients and bioactive compounds, there arises a necessity to delve into methods for its processing and drying. Over recent decades, a significant amount of research has been conducted on the chemical composition of CM and its potential health benefits. Consequently, this study is directed towards examining CM drying technology, including an analysis of the influence of different drying methods on its chemical composition and nutritional properties. The objective of this review is to systematically summarize the available literature on CM drying processes and their impact on its chemical composition. Special attention is devoted to comparing various drying methods such as freeze-drying, spray drying, and freeze-drying, as well as investigating factors affecting the quality of dried CM. To achieve this goal, we scrutinize a series of studies published between 2003 and 2022 to identify optimal drying methods that promote the maximum preservation of CM's nutritional components and bioactive compounds. Additionally, we explore possibilities for reducing drying time to enhance production efficiency. This research is grounded in the analysis of data from diverse scientific research databases, including Scopus and Google Scholar, encompassing a systematic review of scientific literature and a comparative analysis of the obtained results.

Keywords: CM; spry-drying; freeze-drying; powder

1. Introduction

The global consumption of powdered dairy products has seen a significant rise due to their convenience, food safety attributes, and long shelf life. Moreover, these products are extensively traded and primarily manufactured for export purposes. Powdered dairy products find widespread use in various industries, particularly in confectionery, infant formula, and bakery products. These characteristics make them highly suitable for international trade (Rosa and Prudencio 2023). According to the IDF Dairy bulletin, SPM production increased every year and in 2022 increase by 1.3% with 5 000 000 tons (Bulletin_527/2023, 2023).

Camel milk (CM) boasts notably elevated concentrations of iron, vitamin C, and protein, while possessing lower level of lactose compared to cow milk (Tastemirova, Ciprovica, and Shingisov 2020). Additionally, CM is rich in various minerals such as calcium, phosphorus, potassium, sodium, magnesium, manganese, zinc, as well as B vitamins (Siddiqui et al. 2024). Furthermore, CM contains a group of proteins with antiviral, antifungal, and antibacterial properties (Saibhavana et al. 2023). The distinctive composition of its omega-3 fatty acids allows CM to undergo freezing and thawing processes without changing its texture or leading to curdling, a frequent problem encountered with cow's milk (Siddiqui et al. 2024).

CM is a captivating dairy product believed to offer various health advantages and potentially combat human diseases such as diabetes, cancer, hypertension, and autism (Ayoub et al. 2024; Kumar et al., 2016).

 doi:10.20944/preprints202404.0559.v1

CM, sourced predominantly from regions in Asia and Africa (Siddiqui et al. 2024) characterized by hot climates, necessitates strategies to preserve its quality and extend its shelf life, especially considering the potential absence of refrigeration facilities during storage. Given these circumstances, milk drying emerges as a viable alternative for preservation and storage, ensuring the longevity of the product without compromising its quality.

Dehydration and production of milk powders are common practices to stabilize milk constituents for storage and transportation. Parameters like feed solids concentration, milk flow rate, inlet temperature, outlet temperature, and nozzle air pressure significantly affect the properties of milk/dairy powders (Ho et al. 2022).

Dairy powder production involves several processing stages, such as pasteurization, concentration, and dehydration (Ho, 2022). The heat treatments administered at each stage can induce alterations in dairy powder characteristics, such as stability of different milk components (proteins, vitamins, minerals etc), solubility and other physical attributes. Analyzing the quality of dairy powder products is crucial for comprehending and managing potential changes that may arise during storage or transportation (Rosa and Prudencio 2023).

The industry faces challenges primarily associated with creating distinct powdered dairy products while maximizing production efficiency to minimize energy usage and product wastage. Among the various methods for reducing water content on a large scale, two operations stand out: atomization/pulverization (commonly known as spray drying) and freeze-drying processes. Therefore, the objective of this review is to systematically summarize the available literature on CM drying processes and their impact on its chemical composition.

2. Materials and Methods

The review used the monographic method and the English language. The type of review is semi-systematic. The review summarizes the available literature on the chemical composition of CM and possible differences between drying methods for the period from 2003 to 2022. We review the literature on CM drying technology and its chemical composition during drying, and investigate methods to reduce drying time. In this review, we analyse existing studies on different drying methods for CM, including freeze drying and spray drying, as well milk powder quality. We also evaluate the effects of various factors on CM composition during the drying process, such as temperature, drying time and storage conditions. Our work aims to identify optimal drying methods that maximise the retention of nutrients and bioactive components of CM, and to explore ways to reduce drying time to improve production efficiency. For the analysis we studied databases of scientific articles Scopus, google scholar (as in RK the most accessible) covering a wide range of published research results on milk compounds. To search for relevant information, the following key terms were used: vacuum freeze drying, CM, reduced drying time. The review considered 224 full-text articles from Scopus' Sciencedirect database . From google scholar database 1,380 of them 571 were relevant. The authors used a wide range of synonyms to find the most relevant literature.

3. Results and discussion

3.1. CM Characterization and Importance

Chemical composition of CM

The chemical composition of CM differs from that of cow milk. According to Konuspayeva (2009) chemical composition of CM similar to cow milk, but have some differences: total solids 12.47 ± 1.53% (from 8.85% to 16.08%), lactose 4.46 ± 1.03%, fat- 3.82 ± 1.08%, protein - 3.35 ± 0.62%, and minerals - 0.79 ± 0.09%.

Lipids. Consequently, numerous studies (Swelum et al. 2021; Seifu 2023; Narmuratova et al. 2006; Bakry et al. 2021) have been conducted on CM (CM) fat range from 2.46 to 5.70% (Konuspayeva et al. 2009), and its potential effects on human health. The elevated melting point (41.9°C) is attributed to CM fat's composition - high level of long-chain fatty acids, a scarcity of short-chain fatty acids, and trans 18:1 isomers. Furthermore, CM demonstrates a lower saturated fatty acid (SFA) content (46.0-

66.0%) alongside higher levels of monounsaturated fatty acids (MUFAs) (25.7%-49.3%) and polyunsaturated fatty acids (PUFAs) (2.7%-8.5%) compared to cow milk (Bakry et al. 2021). Moreover, CM exhibits smaller fat globules, with an average diameter of 2.61 µm (Bakry et al. 2021). This feature suggests that CM is more easily digested by humans, presenting a potential advantage in terms of gastrointestinal processing.

The prevalence of long-chain fatty acids (LC-FAs) and unsaturated fatty acids in CM contributes significantly to its capacity to reduce the incidence of fat-related cardiovascular ailments by an estimated 35–50%. Intriguingly, CM fat boasts a richer concentration of conjugated linoleic acid (CLA) in comparison to human milk (Bakry et al. 2021). The average cholesterol level of CM was 37.15 mg·100 g^{-1}, it varies within wide range from 25.61 to 50.42 mg·100 g^{-1}, and was found to be lower than that of cow milk (Narmuratova et al. 2006). These investigations have unveiled a positive correlation between CM consumption and human well-being, revolutionizing perceptions of CM fat as a health-promoting food source.

Proteins. Protein concentration in CM range from 2.15% to 4.80% (Konuspayeva et al. 2009). CM predominantly consists of caseins varying from 52.0% to 87.0% of its total protein content, with αS1-casein, αS2-casein, β-casein, and kappa-casein constituting 21%, 10%, 65%, and 3.47% respectively (Swelum et al. 2021). Notably, β-casein contributes to CM's easy digestibility in human infants due to its susceptibility to peptide hydrolysis. Compared to bovine milk caseins, camel caseins exhibit a similar amino acid composition, albeit with lower cysteine and higher proline content (Park and Haenlein 2013).

In addition to caseins, CM whey proteins contain α-lactalbumin, serum albumin, immunoglobulins, lactophorin (GlyCAM-1), and lactoferrin, with concentrations of 2.01, 0.40, and 1.74 mg mL^{-1} respectively (Swelum et al. 2021). These proteins' physiochemical properties and bioactivities, including those of their peptides released during fermentation/digestion, have been extensively reviewed by Kumar et al. (2016). The absence of β-lactoglobulin in CM, similar to human milk, positions it as a promising alternative protein source to human milk and in infant formula, owing to reduced allergenicity (El-Agamy et al. 2009; Swelum et al. 2021; Kumar et al. 2016). The presence of β-LG in bovine whey enhances its heat stability, resulting in poor stability of CM at temperatures up to 140°C in contrast to cow's milk (Swelum et al. 2021). On the other hand, α-lactalbumin (α-LA) constitutes the primary component of camel whey, while bovine whey contains only 25% of this protein. Both camel and human milk are recognized for their high contents of α-LA and lactoferrin (Lf) (Ho et al. 2022). Whey proteins such as IgGs, Lf, lactoperoxidase, lysozyme, and other enzymes are potent antimicrobial components in CM (Swelum et al. 2021; Kaskous 2016; El-Agamy et al. 2009). The antimicrobial properties of CM are attributed to the high content of protective proteins in the whey fraction, known for their superior thermostability (El-Agamy et al., 2009). Consequently, camel whey proteins serve as a novel source of proteins capable of generating bioactive peptides with potential health benefits (Kumar et al. 2016).

Lactose. CM exhibits a lactose content similar to that of bovine milk and range from 2.40% to 5.80% (Konuspayeva et al. 2009). With free access to drinking water, the average lactose content in camels rises to 5%, whereas in dehydrated camels, it decreases to 2.9%. Fluctuations in lactose concentration in CM have been linked to variations in taste, from occasionally sweet to bitter (Ho et al. 2022). Notably, CM appears to be a safer and healthier option for individuals with lactose intolerance, possibly due to factors such as lower casomorphin concentration, which slows intestinal motility and allows lactase action over an extended period (Cardoso et al. 2010). Additionally, CM's reduced lactose intolerance compared to bovine milk may be attributed to its high content of L-lactate in its raw form, which surpasses that of bovine milk by 100 times (Ho et al. 2022).

Ash. The average ash content in CM resembles that of bovine milk but surpasses human milk by a significant margin, and range from 0.60% to 1.05% (Konuspayeva et al. 2009). Major mineral concentrations in CM include calcium (111.4 mg 100 g^{-1}), calcium concentration varied from 30.0 to 250.0 mg 100 g^{-1}, magnesium (6.7 mg 100 g^{-1}) from 4.5 to 20.0 mg 100 g^{-1}, phosphorus (81.2 mg) from 34.0 to 100.0 mg 100 g^{-1}, sodium (57.8 mg) from 22.0 to 69.0 mg 100 g^{-1}, and potassium (156.3 mg) from 52.0 to 180.0 mg 100^{-1} (Konuspayeva et al. 2022), whereas bovine milk shows higher concentrations of calcium, magnesium and phosphorus, 119.9 mg, 13.4 mg, 95.0 mg, respectively. The calcium-to-phosphorus (Ca:P) ratios for camel and bovine milk stand at 1.50 and 1.29, respectively (Ho et al. 2022). Moreover, CM boasts a significantly higher iron (from 10 to 20 mg 100 g-1) concentration compared to bovine milk, being six times higher (Konuspayeva et al. 2022).

Vitamins. CM also hosts a variety of vitamins, including A, C, D, E, and the B group. Vitamin A mean value reported by authors is 100 µg L^{-1} with a range of 50 to 140 µg L^{-1} (Faye, Konuspayeva, and Bengoumi 2019). Significant higher comparing with bovine milk is concentration of vitamin D - 15.6 ng ml^{-1}. Concentration of vitamin E (27.6 µg $100ml^{-1}$) in CM is lower comparing to 33.5 µg $100ml^{-1}$ in bovine milk.

Notably, CM is renowned for its elevated vitamin C content, being three to five times higher than that of bovine milk (Seifu 2023). According to Zhao et al. (2015), consuming one cup of Bactrian milk (250g) provides enough vitamin C to meet 100% of the daily human requirements (Zhao, Bai, and Niu 2015). The concentration of B2 vitamin in CM is similar to that found in bovine milk, at 156 µg $100ml^{-1}$(Faye et al. 2019). Vitamin B3 concentration (391.2 µg $100ml^{-1}$) in CM is notably higher compared to bovine milk, whereas bovine milk contains more vitamins A and B2 (Ho et al. 2022). Vitamin B1 and B6 levels are similar in both camel and bovine milk (Faye et al., 2019).

Functional properties of CM

Hypoglycemic. In regions abundant with camels, CM has been traditionally consumed for treating diabetes, with notable success. Studies have demonstrated a significantly lower prevalence of diabetes in CM-consuming communities compared to non-consuming ones (0% vs. 5.5%) (Ho et al. 2022). Numerous clinical trials have underscored the anti-diabetic effects of CM. Agrawal et al. (2003) reported that type I diabetes patients required 66% less insulin after three months of CM consumption, with long-term efficacy and safety confirmed in 1- and 2-year trials (Kaskous 2016). Additionally, CM appears beneficial for controlling insulin levels in type II diabetes patients, as evidenced by a significant increase observed after two months of CM consumption (Zhao et al. 2015).

Antimicrobial effect. CM demonstrates notable antibacterial activity against a spectrum of bacteria, encompassing both Gram-positive and Gram-negative strains such as *Escherichia coli, Listeria monocytogenes, Staphylococcus aureus, Salmonella typhimurium, Klebsiella pneumonia,* and *Clostridium perfringens* (Ho et al. 2022). It was proved, that CM could protect against the harmful effects caused by *S. aureus* and *E. coli* in rats. Scientists found that CM, when used in conjunction with ciprofloxacin, worked synergistically to combat *S. aureus* and *E. coli*, thereby reducing bacterial resistance and allowing for a decrease in the dosage of antibiotics needed (Kumar et al. 2016). This antibacterial property of CM holds promises in combating diseases caused by bacterial infections, including tuberculosis (TB) and Crohn's disease, viruses (rotavirus, hepatitis C) (Saibhavana et al. 2023). Lactoferrin, lysozyme, and immunoglobulins, which are abundant in CM, primarily contribute to its antibacterial activity (Benkerroum 2010). The examination using scanning electron microscopy (SEM) displayed alterations in the structure of bacterial cells when exposed to lactoferrin. Different forms of lactoferrin demonstrated dose-dependent cytotoxicity against the A549 human lung cancer cell line, indicating potential anticancer properties (Alkhulaifi et al. 2024). Furthermore, enzymatic hydrolysis of camel whey proteins enhances their antimicrobial potency, hinting at the release of peptides with heightened antimicrobial effects post-digestion (Behrouz et al. 2022). Additionally, CM has been attributed with antifungal and antiparasitic activities (Ho et al. 2022).

Immunological effect. Camels possess a distinctive and robust immune system, characterized by antibodies significantly smaller in size compared to those in humans. Notably, CM contains unique IgG2 and IgG3 antibodies lacking light chains (Ho et al. 2022). These antibodies are highly effective in targeting specific antigens, exhibiting complete neutralizing activity against toxins like tetanus toxin and serving as superior inhibitors of enzyme antigens. The underlying mechanisms of autism could potentially include an excess of naturally occurring or externally introduced opioid peptides, which may originate from dietary sources such as cow's milk proteins. Certain patients exhibit inadequate intestinal breakdown of casein proteins, resulting in the production of beta-casomorphins, short neuroactive peptides derived from casein. These peptides, notably beta-casomorphin (Seifu 2023), have been implicated as a potential risk factor for autism (Saibhavana et al. 2023; Seifu 2023; Behrouz et al. 2022). Remarkably, CM therapy has shown promising effects on the behavior of autistic children, potentially linked to its ability to combat oxidative stress. After two weeks of CM consumption, autistic children exhibited significant increases in plasma concentrations of glutathione, myeloperoxidase, and superoxide dismutase, indicative of improved oxidative stress control. The rehabilitative effect of CM's immunoglobulins is believed to contribute to alleviating potential dairy food allergies in autistic children, further highlighting its therapeutic potential (AlAyadhi et al., 2013; Shabo & Yagil, 2005).

Hypoallergenity. Bovine milk allergy represents a significant concern among both children and adults, with clinical symptoms ranging from mild to severe. With over 20 proteins capable of triggering allergic reactions, casein fractions, particularly αS1-casein, and β-lactoglobulin are identified as the most potent allergens within bovine milk (Saibhavana et al. 2023). In contrast, human milk composition lacks β-lactoglobulin, and αS1-casein is present in low concentrations, while β-casein is notably abundant (Ho et al. 2022). The protein profile of CM closely resembles that of human milk, indicating its potential as a viable alternative for individuals with bovine milk allergies. Promising outcomes from clinical trials support the use of CM in treating milk allergies in children (Saibhavana et al. 2023). Moreover, CM has been suggested as a preferable option for those with lactose intolerance due to its rapid lactose digestion (Saibhavana et al. 2023; Ho et al. 2022; Cardoso et al., 2010). However, broader-scale trials are necessary to substantiate these claims further.

3.2. Drying methods for CM

3.2.1. Spray-drying

Spray drying can be considered a dehydration process due to the property of the encapsulation technique. Depending on spray drying set-up parameters powder can be classified into small size (1–5 μm), medium size (5–25 μm) and large size (10–60 μm) crystals. The main impact on crystal size is the atomization condition, such as droplet size (Piñón-Balderrama et. al., 2020). Spray drying of CM has been found to have a lower impact on the physical properties of the milk powder compared to freeze drying (Tastemirova et. al., 2020). However, the process must be optimized to retain the nutritional properties and techno-functional characteristics of the powder (Habtegebriel et. al., 2018). The spray drying conditions, such as inlet temperature and atomization pressure, can affect the yield and nutritional components of the milk powder (Habtegebriel et. al., 2018). The changes in physicochemical, functional, moisture sorption, and morphological characteristics of CM powder due to spray drying have also been investigated (Deshwal et. al., 2020). It has been found that the inlet drying air temperature and the milk flow rate influenced the thermal, optical and physical properties of laboratory spray-dried powders (Ogolla et al., 2019).

Compared to bovine milk powder, spray-dried CM powder has been found to have a lower protein denaturation extent and different water sorption properties (Zouari 2020).

CM spray-dried powder typically contains 29 - 45% lactose, as it's shown in Table 1. This range is influenced by various factors such as geographical origin, breed, and lactation stage. CM powder is a rich source of protein, with a composition that includes α-lactalbumin, lactoferrin, serum albumin, and caseins (Omar et. al., 2016). The protein content in CM powder based on data in Table 1 is around 26 % (Kanhal et.al., 2010), which is lower than that of cow and buffalo milk powder (Yoganandi et.al., 2014). However, the specific protein amount in CM powder may vary depending on the processing method and the addition of other ingredients. CM powder contains also a significant amount of fat, with Table 1 reporting a range of 20% to 29% fat content. The fat in CM is primarily composed of triacylglycerols, with a high proportion of saturated fatty acids (Gorban et. al., 2001). This makes CM powder a rich source of healthy fats, which can be beneficial for those consumers who are looking to increase their fat intake. The findings in Ogolla et. al 2019 report indicated that the inlet drying air temperatures significantly influenced the moisture content and colour properties of the powders (Ogolla et al., 2019).

 doi:10.20944/preprints202404.0559.v1

Table 1. Spray dried CM powder composition.

protein	fat	lactose	moisture content	Reference
25.0% (w/w)	23.0% (w/w)	45.0% (w/w)	5%	Ho et. al., 2021
24.10 – 26.73 %	27.86 – 29.24 %	nm	1.01 – 2.41 %	Sulieman et. al., 2014
31.6 %	29.06%	29.6%	nm	Habtegebriel et. al., 2018
27.4%	28.2%	32.6%	2.43%	Deshwal et al. 2020
24.3%	20.5%	43.4%	nm	Zouari et. al., 2020
22.0 – 29.0%	10.0 – 14.0%	27 – 31%	3.00 – 4.50%	Habtegebriel et. al., 2021

Table 2. Spray dried parameters for CM.

Inlet temperature	Outlet temperature	Feed rate and temperature	Reference
160°C	70°C	55 mL/min and 25 °C	Ho et. al., 2021
200°C – 220°C	98°C -105°C	-	Sulieman et. al., 2014
170 ± 5 °C	70 ± 5 °C	50 mL/min and 50 °C	Deshwal 2020
160 °C – 200°C	-	3,3 – 16,7 mL/min	Zouari 2020

To have the most effective moisture removal from the CM the inlet temperature should be chosen properly high. Nevertheless, temperature should not impact and cause thermal damage to the active compounds in milk. Additionally, a high inlet temperature also helps to prevent particle agglomeration, particle adhesion on the walls of the drying chamber, and microstructure collapse. Outlet temperature depends mainly on product properties and the processes formed during the drying, such as gas inlet temperature, gas flow rate, enthalpy of evaporation, and concentration of milk solids. Feed rate has a direct effect on particle size, the higher is feed rate the larger are particles.

The kinetics of the spray drying process are complicated and challenging. Particle size and characteristics are dependent on numerous factors during this process.

3.2.2. Freeze-drying method

Freeze drying is a common process used to produce CM powder because it may preserve the integrity of bioactive chemicals at low drying temperatures, protecting the end product's quality. This method is essential for increasing the usability and accessibility of CM in a range of applications. It has been discovered that the nutritional qualities of freeze-dried CM are significantly different from those of fresh milk, having increased levels of total protein, casein, whey proteins, lactose, and ash (Ibrahim, 2015). Significant modifications in CM powder's physico-chemical, functional, moisture-sorption, and morphological characteristics have been identified in studies that examine the specific impacts of freeze-drying (Deshwal, 2020). This method affects the powder colour features, improves the insolubility index, and flowability (Sulieman, 2018).

Table 3. Freez dried parameters for CM.

initial freezing	pressure	Reference
– 45 °C	0.10 mbar	Ibrahim & Khalifa, 2015
– 55 - – 65 °C	1.65 mbar	Deshwal, et. al., 2020
– 50 °C	0.05 mbar	Harizi et. al., 2023
– 40 °C	1.00 mbar	Rahman et. al., 2012
– 55 °C	0.20 mbar	Zou, et. al., 2022
– 40 °C	1.00 – 3.00 mbar	Sunooj et. al., 2011
– 108 °C	0.004 mbar	Aralbayev et. al., 2019 Aralbayev et. al., 2021

The process of freeze-drying CM offers several benefits. One of the features of freeze-drying is it can stop the Maillard process and denaturation of whey protein while preserving heat-sensitive

 doi:10.20944/preprints202404.0559.v1

chemicals (Deshwal, et. al., 2020). On the other hand, there is a high possibility that using the freeze-drying process additionally with a vacuum significantly reduces the reduction of thermolability of protein and the amino acid composition of CM (Tastemirova et.al., 2022). The process can also influence milk powder particles which can hardly be disintegrated and full solubility has not been achieved (Tastemirova et. al., 2020).

Compared to other dehydration techniques, freeze-drying takes a longer period. The process of freeze-drying CM usually takes longer than expected, which might impact turnaround time and production efficiency. While many of the nutritional and practical qualities of CM are retained during the freeze-drying process, some of the volatile chemicals that give the milk its flavour and perfume may be lost. This may have an impact on the finished product's sensory attributes, possibly resulting in variations in flavour when compared to fresh milk (Harizi et. al., 2023). Optimising the freeze drying process of camel milk is key to improving production efficiency and maintaining the quality of the final product. The duration of the freeze drying process is often longer than expected, which can negatively impact turnaround times and overall production productivity. In addition, although most of the nutritional and practical characteristics of camel milk are retained during the freeze drying process, some of the volatile substances that give the milk its flavour and aroma may be lost. This may affect the organoleptic properties of the final product, leading possibly to changes in flavour compared to fresh milk. Thus, optimising the freeze drying process will reduce production time, improve the quality of the final product and provide more consistent organoleptic characteristics.

Table 4. Freeze dried CM powder composition.

protein	fat	lactose	moisture content	Reference
26% (w/w)	25% (w/w)	40% (w/w)	3 %	Sunooj et. al., 2011
28 %	28 %	31 %	3 %	Deshwal et al. 2020
26 %	26 %	37 %	3 %	Ibrahim & Khalifa, 2015
25 %	23 %	nm	3 %	Tastemirova et. al., 2020

According to the study, freeze-dried CM had greater amounts of iron and calcium than spray-dried milk (15.3 and 0.012 g/kg, respectively) (Deshwal, et. al., 2020). Freeze-drying eliminates moisture, which stops enzyme activity and microbiological growth—two main causes of food degradation. As a result, the product has a longer shelf life than fresh milk and may be stored for a long time without needing to be refrigerated. (Zou, et. al., 2022). There are multiple processes involved in the process of freeze-drying, and temperature, pressure, and other variables must be carefully monitored at all times.

Vacuum dehydration usually is combining with freeze-drying takes place at less low temperatures, with a notably elevated medium pressure, and without the need for the material to be freeze-dried first. This results in a good final product quality and notable energy efficiency. The characteristics of the heat transfer mechanism during vacuum drying are typically determined by the vacuum level, which is usually in the medium to low range (Abdizhapparova et. al.,2022).

Tastemirova and co-authors reviled that drying CM causes a partial denaturation of its amino acid composition, which results in a decrease in the amount of low molecular weight protein fractions and an increase in higher molecular weight protein fractions. The amount of other nonessential amino acids decreased as follows, whereas the amount of arginine increased 2.53 times: 13.16 times for glycine, 2 times for proline, 6.34 times for alanine, and 2.26 times for serine. The whey protein components like albumin and globulin fractions are particularly vulnerable to denaturation alterations, which disrupt the hydration membrane of proteins on the surface and cause slight variations in the composition of amino acids (Tastemirova et. al., 2022).

The amount of saturated fatty acids in the CM powder decreased during vacuum freeze drying at a sublimation temperature of -15 °C, except for capric, tridecylic, and heneicosanoic acids. An increase in the amount of unsaturated fatty acids was noted, which was related to structural variations in the fatty acid phase of CM during the vacuum-freeze drying process (Tastemirova et. al., 2022).

 doi:10.20944/preprints202404.0559.v1

Additionally, with this drying method, insignificant changes in milk powder contents of vitamins and macroelements. For instance, vitamin B1 (thiamine) is decreased by 7.69%, while vitamin B2 (riboflavin) is more than doubled and vitamin B6 (pyridoxine) is decreased by 22.22%. The major losses are in vitamin C (ascorbic acid), which is lost more than three times (Tastemirova et. al., 2022).

Table 5. Brands offering CM powder.

Company	Description
Camelicious	Camelicious is a well-known brand based in the United Arab Emirates. They offer various CM products, including CM powder, known for its quality and purity.
Desert Farms	Desert Farms is another prominent brand specializing in CM products. They offer CM powder sourced from family-owned camel farms, primarily in the United States.
CM Co Australia	This Australian-based company focuses on providing pure and natural CM products, including CM powder.
Vital CM	Vital CM is a brand offering CM powder and other CM products. They emphasize the nutritional benefits of CM.
QCamel	QCamel is an Australian brand known for its premium CM products, including CM powder. They pride themselves on sustainable farming practices.
CM Powder UK	This brand, as the name suggests, offers CM powder in the United Kingdom. They claim to provide high-quality CM powder sourced from reputable suppliers.
The CM Factory	Based in Dubai, The CM Factory produces a range of CM products, including CM powder, which is processed using advanced technology
Camelicious USA	Camelicious USA is a branch of the well-known Camelicious brand, offering CM powder and other CM products to the American market.

In this table are listed some of the worldwide companies that manufacture and sell CM powder. The powder is produced using either spray or freeze-dry technology. In addition, the table shows the global companies that produce and sell camel milk powder. These companies offer products derived from both spray-drying and freeze-drying, emphasising the quality, purity and nutritional properties of their products.

Overall, the freeze-drying process of camel milk continues to attract attention as a potentially important method of preserving and transporting this valuable product. However, it is important to consider the loss of certain vitamins and important nutrients during the drying process, which could potentially affect the nutritional value of the final product. It is also important to note that there are many companies offering camel milk powder on the market, indicating a growing interest in this product and its popularity among consumers.

Overall, further research and technology development in the production and drying of camel milk powder can help improve the quality and preservation of this product, which in turn can lead to the expansion of its potential applications and market popularity.

4. Conclusions

In conclusion, the development of new technology for CM drying holds significant importance and potential for the food industry. CM possesses unique nutritional properties and is utilized in various food products and beverages, but its drying process is complex and energy-intensive. The introduction of new drying technologies based on advanced computational methods and innovative approaches can significantly improve production efficiency and environmental sustainability.

Further research in this field is crucial for advancing CM drying technologies. Continued studies in computational fluid dynamics, multiphysics modeling, and material properties are essential for more accurate modeling of the drying process. Additionally, practical implementation of research findings will enable successful integration of developed technologies into production processes, yielding tangible benefits.

Only through ongoing research, development of new methods, and their practical application can we achieve more efficient and environmentally friendly CM drying. This ultimately leads to improved product quality and enhanced competitiveness in the market.

However, further research is needed to determine the optimal sublimation temperature, considering both the preservation of nutritional substances and the energy efficiency of the drying process. This will ensure the highest product quality while optimizing resource utilization.

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