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Impact of spray-drying conditions on physicochemical properties and rehydration ability of skim dromedary and cow's milk powders

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ABSTRACT

The effect of spray-drying conditions on physicochemical and rehydration ability of skim dromedary and cow's milk powders was evaluated. Two sets of spray-drying conditions were applied on skim dromedary and cow's milks to determine the effect of air outlet temperature (75 and 85 °C) and milk type on proximate composition, water activity, particle size distribution, color, and rehydration ability of spray-dried powders. While the water activity of powders was close to 0.4 for a production at 75 °C air outlet temperature, it ranged from 0.2 to 0.3 for a production at 85 °C air outlet temperature. Skim dromedary milk powder had a lower water activity than skim cow's milk powder after spray-drying at 85 °C air outlet temperature. The particle size distributions of spray-dried skim milk powders were centered around 14 - 20 μm . The particles of skim dromedary milk powders were smaller than those of skim cow's milk powders as skim dromedary milk was less viscous, leading to smaller sprayed droplets. Whatever the spray-drying conditions and the milk type, the produced powders were very bright and had a low color saturation. Scanning electron microscopy images showed that spray-dried powders appeared as agglomerates of small particles with angular shapes rather than individual particles. All investigated spray-dried powders were considered non-wettable, hardly dispersible, and fairly soluble. These results demonstrated that the outlet drying air temperature significantly influenced the physical and rehydration properties of spray-dried dairy powders.

Keywords: spray-drying; dromedary milk; water activity; particle size distribution; rehydration ability; SEM

INTRODUCTION

In recent years, a great attention has been paid to the health benefits of dromedary milk, which constitutes an important nutrition source for inhabitants in arid and semi-arid areas.^[1] Dromedary milk has been proven to contain great amounts of essential fatty acids, vitamin C as well as natural immune-active proteins such as lactoferrin, lysozyme, immunoglobulins, and lactoperoxidase.^[2] The proximate composition of cow's and dromedary milks is similar. However, dromedary milk is higher in β -casein and lower in κ -casein, making it less suitable for cheesemaking. Moreover, β -lactoglobulin, which is very important for infant nutrition, is absent from dromedary milk.^[3]

The preservation of dromedary milk involves many processes such as thermal treatment ^[4,5], acid coagulation ^[6], and microbiological fermentation ^[7]. Many derivative products of dromedary milk have been developed, such as butter ^[8] and yogurt.^[9] Although these products are stable, they have a short shelf-life due to their sensitivity to physicochemical, biochemical, and microbiological degradations during storage.^[10] Therefore, the production of dromedary milk powders could contribute to increase the shelf-life of milk derivatives.

Spray-drying is the most used drying process in all food sectors including dairy products, cereals, vegetables, and eggs.^[11-13] Spray-drying is a matured drying technique with a still significant potential for continued development.^[14] The spray-drying process is suitable to dry dairy products due to the short drying time and the ability to obtain a powdered product.^[15] In the dairy industry, spray-drying is employed not only to increase the stability of milk products during their storage, but also to facilitate their later use. As observed for bovine milks, the spray-drying process is an excellent option for extending the shelf-life of dromedary milk by converting milk into powder without much changing its nutritional and sensory characteristics.^[15, 16]

However, to the best of our knowledge, only few studies have investigated the impact of spray-drying on dromedary milk properties.^[17,18] Smits et al.^[19] have shown that spray-drying of raw whole dromedary milk did not cause any noticeable damage to its protein fraction and dromedary milk powder had a higher solubility than cow's milk powder. Similarly, Zouari et al.^[20] have reported that the spray-drying process induces a mild heat treatment, preserving the protein quality of dromedary and cow's milks.

Most of these studies have focused on the evaluation of the physicochemical properties of dromedary milk powders. The number of studies about the influence of spray-drying conditions is very limited. In fact, Zouari et al.^[21] studied the effect of air outlet temperature and milk fat content on the physicochemical characteristics of spray-dried dromedary milk powder. Recently, Habtegebriel et al.^[16] investigated the effect of pretreatments of the feed concentrate prior to spray-drying on cyclone recovery and the physicochemical properties of dromedary milk powders. These authors reported that operating at less severe processing temperature during spray-drying is necessary to retain higher solubility of dromedary milk proteins. They also showed that dromedary milk powders had higher bulk densities than cow's milk powders processed under similar drying conditions. Furthermore, Ogolla et. al.^[22] studied the influence of inlet drying air temperature and milk flow rate on the physical, optical, and thermal properties of spray-dried dromedary milk powders. They reported that the inlet drying air temperatures significantly influenced moisture content and the color properties of the powders. Indeed, with the increase in inlet drying air temperatures and a decrease in milk flow rate, the moisture content and the brightness of dromedary milk powders significantly decreased. They also showed that particle morphology was affected by the nature and composition of the feed, degree of heat treatment, and spray-drying parameters (inlet drying air temperature and milk flow-rate).^[22]

Spray-drying operating conditions play a key role in the functional properties of cow's milk powder. The properties of cow's milk powder vary considerably depending on the type and composition of the powder, as well as the process conditions of concentration and drying processes.^[23] The reconstitution properties of cow's milk powder such as solubility, wettability, and dispersibility are mainly affected by the inlet drying air temperature and the dry extract of the feed concentrate.^[23]

In the present study, two sets of spray-drying process conditions were applied on skim dromedary and cow's milks to evaluate the impact of process conditions and milk type on physicochemical properties (proximate composition, water activity, particle size distribution, and color) and rehydration ability of spray-dried powders.

MATERIAL AND METHODS

Dromedary and cow's milks

Dromedary (*Camelus dromedarius*) milk was obtained from a local breeding located in the south of Tunisia (Gabès governorate, Tunisia). Dromedary milk constituted of pooled milk samples assembled from twenty different healthy dromedaries, whose lactation time ranged between 2 and 8 months. As for the cow's milk, which was provided by a farm located in the north-east of France (experimental domain of La Bouzule, ENSAIA, Laneuvelotte, France), it was collected from healthy Holstein cows. Both milks were collected in sterile milking cans and 0.02 % (w/w) sodium azide was added to ensure their microbiological stability. Both milks were skimmed at $3\,000 \times g$ during 20 min at 4 °C (Gyrozen 1580MGR, Multi-purpose Centrifuge, Daejeon, Korea). Then, both skim milks were stored at -20 °C until use for spray-drying.

Spray-drying of skim dromedary and cow's milks

Skim dromedary and cow's milks were sieved at 50 μm mesh size (stainless steel, 200 mm diameter, 50 mm height, Retsch GmbH, Germany) in order to remove the potential remaining coalesced fat globules. The spray-drying of skim milks was performed in a MicraSpray MS 150 simple effect pilot plant spray-dryer (Anhydro, Soeborg, Denmark) equipped with a bi-fluid nozzle (Fluid Cap 60 100 + Air Cap 120, Spraying System, Wheaton, Illinois, USA). Aspiration rate was set at 70 % for all performed assays, corresponding to 155 kg.h^{-1} drying air flow rate. The spray-dryer was fed at 27 °C with a FAST Load peristaltic pump (VWR, Leuven, Belgium, 48 mm internal pipe diameter). The drying air cocurrently flowed with the spray of milk droplets in the drying chamber (Figure 1). Two assays differing in spray-drying conditions (30 L milk per assay) were carried out with a view to evaluate the influence of air outlet temperature (Table 1). The spray-drying conditions were selected based on literature [11] and after preliminary experimentations in order to obtain skim milk powders suitable for storage (i.e. having a moisture content not exceeding 5 % (w/w) and water activity values ranging between 0.2 and 0.4).^[11]

The powders were then collected, immediately packed in polyethylene terephthalate bags and stored at 10 °C until analysis. All analyses were carried out within a week after powder production. Spray-drying yield was calculated as the ratio between the dry mass of powder and the dry mass of feed skim milk.

Proximate composition of skim dromedary and cow's milks

Dry matter, protein, and ash contents of skim dromedary and cow's milks were performed according to the AOAC standard methods.^[24] Dry matter was determined by drying 10 mL milk at 103 °C for 5 h in a capsule containing Fontainebleau sand (1:10 (w/w) milk sample/Fontainebleau sand). Ash content was determined by weight loss after incinerating 10 mL milk sample in a furnace at 550 °C during 6 h. The total nitrogen content was determined

according to Kjeldhal method (10 mL of milk sample), and protein content was deduced from total nitrogen content by multiplying by a conversion factor of 6.38. Fat content was determined according to the Gerber acid-butyrometric method (11 mL of milk sample). Carbohydrates content was deduced by difference with other components according to equation 1 assuming that vitamins were weakly represented:

$$\text{Carbohydrates content (\%)} = 100 - (\text{moisture content} + \text{protein content} + \text{ash content} + \text{fat content}) \quad (\text{Equation 1})$$

Dynamic viscosity of skim dromedary and cow's milks

The dynamic viscosity of dromedary and cow's skim milks was determined at 4 °C using the Malvern Kinexus oscillatory rheometer (Malvern Instruments, Orsay, France) using cone-plane geometry at shear rates ranging from 0.1 to 1 000 s⁻¹ during 20 min.

Proximate composition of skim dromedary and cow's milk powders

Moisture, protein, and ash contents of skim dromedary and cow's milk powders were performed according to the AOAC standard methods.^[24] Moisture content was determined by weight loss after drying 3 g powder in an air oven at 105 °C for 7 h. Ash content was obtained by weight loss after incinerating 3 g powder in a furnace at 550 °C during 6 h. The total nitrogen content was determined by the Kjeldahl method (0.1 g of milk powder) (Vapodest, Gerhardt GmbH & Co. KG, Königswinter, Germany) and protein content was deduced from nitrogen content by multiplying by a conversion factor of 6.38.

Fat content was determined using the Folch method^[25] by performing solvent extraction of 2 g powder using a mix of 2:1 (v/v) chloroform/methanol.

Carbohydrates content was deduced by difference with other components according to equation 1 assuming that vitamins were weakly represented.

Water activity

Water activity of spray-dried powders (10 g) was measured using a water activity meter (HygroPalm23-AW, Rotronic, France) in quick mode at 25 °C.

Particle size distribution

Particle size distributions of skim dromedary and cow's milk powders were determined with a laser granulometer (Mastersizer 3000 Malvern Instruments, UK), equipped with He-Ne laser light (632.8 nm wavelength), using dry dispersion with the Aero S module. Dispersion conditions were as follows: 2 bar, 100 % air pressure, 100 % feed rate, and 3 mm hopper length. The median diameter in volume was chosen as particle size estimator. Classical granulometric parameters D_{10} , D_{50} , and D_{90} were recorded (D_X corresponds to the size for which X % of the particle population has smaller size). Span was calculated to evaluate the width of the particle size distribution (equation 2):

$$Span = (D_{90} - D_{10}) / D_{50} \quad (\text{Equation 2})$$

Colorimetric analysis

The color of skim dromedary and cow's milk powders was measured using a colorimeter (Konica Minolta, Inc, Japan) in the CIEL*a*b* system. The colorimetric parameters L^* (lightness), a^* (redness/greenness), and b^* (yellowness/blueness) were determined. L^* , varying from 0 to 100, describes sample lightness (low values for darkness, high values for lightness). a^* varies from -100 to 100 and represents the green-magenta color scale, with negative values for greenness and positive values for redness. b^* ranges from -100 to 100 and corresponds to the blue-yellow color scale, with negative values for blueness and positive values for yellowness. The chroma (C^*) and hue angle (H°), representing the saturation level and shade of the color, respectively, were calculated as follows (equations 3 and 4).^[26]

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (\text{Equation 3})$$

$$H^{\circ} = \arctan (b^{*}/a^{*}) \text{ (Equation 4)}$$

Scanning electron microscopy

The morphological properties of skim dromedary and cow's milk powders were determined using scanning electron microscopy (Hitachi S-4800, Japan) operated at 1 kV. Powders were stuck onto the adhesive carbon tabs (JEE-420, Japan). The milk powder samples were then coated with carbon. Topographic images were taken for each milk powder at different magnifications (200 ×, 600 ×, 2 000 ×, 10 000 ×, and 45 000 ×).

Rehydration properties

Solubility index

Solubility represents the mass percentage of soluble matter in powders, it was determined according to ISO 8156:2005 standard method.^[27] First, 2.5 g skim milk powder was vigorously mixed with 17.5 mL distilled water at 22 °C in a Falcon tube during 30 s. The suspension was then centrifuged at 1 800 × g (Heraeus Megafuge 8R Centrifuge, Germany) at room temperature (22 °C) and the supernatant was collected. The supernatant dry matter was determined by drying at 103 °C in an air oven for 15 h. The solubility index SI was determined using the following equation 6:

$$SI (\%) = 100 - (M * 100/2.5) \text{ (Equation 6)}$$

Where M designates the sediment mass (g).

Wetting time

The wetting time is defined as the time expressed in seconds required for a powder to become completely wet.^[28] It was determined by gently pouring 26 g powder at the surface of 250 g distilled water at 20 °C in a 250-mL beaker.

Dispersibility index

The dispersibility index (DI) is the amount of dry matter that can be dispersed in water, expressed as a mass percentage.^[28] To evaluate the dispersibility index, 26 g powder was added to 250 g distilled water at 20 °C and the mixture was stirred with a spatula for 20 s. A filtration of the mixture was carried out using a metallic sieve. The dispersibility index DI was determined using the following equation 7:

$$DI = \frac{T \times 962}{100 - (W + T)} \text{Equation (7)}$$

With T: dry matter content of the resulting liquid (% (w/w));

W: moisture content of the powder sample (% (w/w)).

Statistical analysis

All analyses of this study were carried out in triplicate and reported values were means $\pm$ standard deviations. Statistical analysis was performed using the DSAASTAT add-on for Excel 2010 (Microsoft, Redmond, USA). The presence of significant differences between sample results was investigated by one-way ANOVA and the means were separated by Tukey's HSD test at $p \leq 0.05$.

RESULTS AND DISCUSSION

Proximate composition of skim dromedary and cow's milks

The proximate composition of skim dromedary and cow's milks is summarized in Table 2. The proximate composition was significantly different between milk samples. Total solids content was significantly lower for skim dromedary's milk (9.52 % (w/w)) than for skim cow's milk (12.05 % (w/w)). Protein and ash contents were significantly higher for skim dromedary's milk. Carbohydrates content was significantly lower in the case of skim dromedary's milk. These differences could be attributed to the milk type, animal feed, geographic location, and veterinary practices.^[1] Similar results were obtained by Al Haj and Al Kanhal^[1] who reported

that ash content of dromedary milk ranged between 0.60 and 0.90 % (w/w) on dry basis. Zouari et al.^[21] obtained similar results for proteins and ash but lower carbohydrates (lactose) content for skim dromedary and cow's milks. The proximate composition of skim cow's milk obtained in the current study was in agreement with the ranges of proximate composition of skim cow's milk reported by other researchers.^[16] Although both milks were skimmed in the current study, the fat content of both samples was still higher than that usually observed for skim dromedary and cow's milks. These results could be justified by the fact that the conditions used for milk skimming by centrifugation in this study were soft compared to what is commonly realized in the literature. Therefore, both milks were considered to be partially skim milks.

Proximate composition of skim dromedary and cow's milk powders

Table 3 displays proximate composition, water activity, and spray-drying yield for skim dromedary and cow's milk powders. Total solids content, ranging from 92.96 to 97.01 % (w/w), significantly differed between all spray-dried skim milk powders. Both skim dromedary and cow's milk powders resulting from the second spray-drying assay led to the highest proportions of total solids (97.01 and 96.63 % (w/w), respectively). This was consistent with the fact that a higher air outlet temperature generally induces the formation of powder with a higher total solids content.^[11] According to Chever et al.^[29], the total solids content of milk powder is affected by milk proximate composition, the air outlet temperature during spray-drying, and the residence time in the spray-dryer. It has also been reported that a small increase in the air outlet temperature during spray-drying can have a substantial effect on powder moisture content. In fact, a temperature increase of 1 °C is reported to cause a decrease in powder moisture content of 0.2 % (w/w) on wet basis.^[11,30] Similar results have been reported by Habtegebriel et al.^[16] for skim dromedary milk powder, Langrish et al.^[31] for skim cow's milk powder, and de Oliveira et al.^[32] for whole goat milk powder. Spray-drying conditions did not have a significant

impact on the proximal composition of studied milk powders. As it can be seen from Tables 2 and 3, the proximate compositions of skim milk powders are comparable to those of their corresponding milks. Besides, protein contents of skim milk powders were neither significantly affected by the milk type nor by spray-drying conditions. The protein contents reported for skim dromedary milk powders spray-dried at 75 and 85 °C were equal to 22 and 23 % (w/w), respectively. The lower protein contents obtained for skim dromedary milk powders could be attributed to the lower protein content of dromedary milk used to feed the spray-dryer. Habtegebriel et al.^[16] showed that spray-dried skim dromedary milk powders contained 44 - 49 % (w/w) proteins. The higher total lipids content of produced powders might explain the lower content in proteins found in the present study. Although no significant difference was observed in ash content between skim dromedary and cow's milks (Table 2), spray-drying process conditions had a significant impact on ash content (Table 3). The ash contents of skim dromedary milk powders of the current study were similar to the 10 % (w/w) ash content reported by Habtegebriel et al.^[16] for skim dromedary milk powder. For skim cow's milk powders, the obtained ash contents, ranging from 6.41 to 6.63 % (w/w), were a little lower than those reported by Deeth and Hartanto^[33], ranging from 7.5 to 8.0 % (w/w).

The water activity of spray-dried powders was mainly affected by spray-drying conditions. In fact, it was close to 0.4 at 75 °C air outlet temperature, whereas it ranged between 0.2 and 0.3 at 85 °C air outlet temperature. This was consistent with the fact that powder water activity is negatively correlated with total solids content,^[11] which was also observed in this study. Skim dromedary and cow's milk powders had close water activity after spray-drying at 75 °C air outlet temperature, but skim dromedary milk powder had a lower water activity than skim cow's milk powder after spray-drying at 85 °C air outlet temperature. Water activity is an important parameter for food preservation. At water activities around 0.3, microbiological growth, lipid oxidation, and Maillard reaction have very low reaction rates.^[34] It has been shown

287 that a water activity between 0.2 and 0.3 at 25 °C is suitable to achieve optimal stability of milk
288 powders.^[34] Therefore, in our study, it was noticed that the conditions of the second spray-
289 drying assay (85 °C air outlet temperature) were more favorable to the preservation of skim
290 dromedary and cow's milk powders.

291 The spray-drying yield is an important parameter for the cost-effectiveness of food
292 preservation. For all spray-drying conditions, the process yields reported in this study (Table 3)
293 seemed to be low for several reasons. Indeed, the pilot spray-dryer used in this study has a large
294 wall area relative to the drying room volume compared to industrial equipment, which promotes
295 material loss by wall sticking. Besides, the low total solids content of the feeding concentrate
296 (skim milk here) contributes to the formation of small-sized particles.^[35] A non negligible
297 proportion of the powder was therefore not retained by the cyclone and escaped with the outlet
298 air. Finally, the presence of residual fat could also favor the stickiness of produced powders.^[31]
299 Powder stickiness is the primary factor affecting the spray-drying yield. A sticky powder is able
300 to adhere to the walls of the spray-drying chamber, enhancing material losses. Stickiness occurs
301 when using drying temperatures slightly over the glass transition temperature of lactose in
302 milks, i.e. in the temperature range comprised between lactose glass transition temperature
303 (55.6 °C) and about 30 °C over.^[36] Recently, Zouari et al.^[21] reported that using an air outlet
304 temperature of 76.5 °C, the glass transition temperatures were 40 and 37.8 °C for skim
305 dromedary and cow's milk powders and 40 °C, respectively. With the increase in air outlet
306 temperature up to 86.8 °C, the same authors obtained glass transition temperatures of 44 and
307 41.5 °C for skim dromedary and cow's milk powders, respectively. Based on these results, it
308 can be concluded that the two air outlet temperatures used in our study were over the sticky
309 points of skim dromedary and cow's milk powders, thus leading to a great proportion of powder
310 loss by sticking to the spray-dryer walls. The residual fat and the fineness of produced powders
311 could probably explain the low spray-drying yields. If the spray-drying operation lasted longer,

the processing yields would have been improved because the spray-dryer walls would have been covered with powder after a moment, which could thereafter limit the deposition of new powder particles.

In the present study, spray-drying yields were greater at the higher air outlet temperature (85 °C), especially for skim dromedary milk powders (51.26 % at 85 °C outlet air temperature vs 19.81 % at 75 °C outlet air temperature). Spray-drying yields were significantly negatively correlated to water activity (Pearson's correlation coefficient r of 0.94). Therefore, it was noted that spray-drying conditions had a greater effect on dromedary milk powders. In accordance with these results, De Oliveira et al.^[32] reported that higher yields are obtained at lower relative humidity of the outlet air, i.e. when the outlet temperature is high and/or the feed flow-rate is low. Habtegebriel et al.^[16] also reported that the increase in the air outlet temperature is likely to enhance cyclone recovery. Actually, it can be predicted that it increases heat and mass transfer in the drying air, thus improving the drying rate and limiting powder stickiness. Similar results were reported by Gallo et al.^[37] who found that the drying air and feed flow-rates as well as the outlet temperature are determinant for the spray-drying yield.

Particle size distributions of skim dromedary and cow's milk powders

Particle size distribution is a very important physical property of milk powders, known for its significant impact on the reconstitution properties of milk powders. Indeed, large particles within a narrow particle size distribution could enhance the rehydration properties of milk samples.^[38] Particle size distributions and granulometric parameters of spray-dried powders are respectively displayed in Figure 2 and Table 4, respectively.

The particle size distributions of spray-dried skim milk powders were monomodal and centered around 14 - 20 μm , consistently with previous results obtained with the same combination of pilot spray-dryer and bi-fluid nozzle.^[39,40] The dispersion of particle sizes around the median value was relatively low, as indicated by the moderate values of span ranging

from 1.75 to 1.93. Although the spray-drying conditions seemed not to influence the particle size distribution, it was noted that the particles of skim dromedary milk powder were smaller than those of skim cow's milk powders. Furthermore, the higher total solids content of feed skim cow's milk may justify this result. Indeed, its viscosity was higher (3.89 ± 0.12 mPa.s) than that of feed skim dromedary milk (2.96 ± 0.13 mPa.s) (Table 2), leading to larger sprayed droplets,^[35] resulting in larger spray-dried particles. Another cause may be attributed to the higher fat content of skim cow's milk powder, which makes it stickier. In fact, fat, composed of sticky components (with a fusion temperature inferior to 80 °C), is known to concentrate at particle surface during spray-drying due to buoyancy in sprayed droplets,^[41-44] making them more prone to agglomeration, thus leading to particle size increase. According to Fournaise et al.^[45], D_{50} of whole cow's milk powder produced in similar spray-drying conditions was 27.7 µm with a span of 3.0, which is consistent with the present study. At last, the higher total solids of feed cow's milk may have limited particle shrinkage during drying owing to the faster solidification of surface-active molecules located at the droplet/particle surface (caused by the higher molecular concentration at the droplet/particle surface and the lower mass transfer inside the droplet/particle due to its higher viscosity), thus also acting in favor of higher particle size. Significant differences were obtained for the granulometric parameters of spray-dried powders, both owing to milk type and spray-drying conditions. No significant influence of spray-drying conditions was observed for dromedary skim milk powders. However, when increasing the air outlet temperature, cow's skim milk powders presented slightly higher median particle sizes. The difference was statistically significant, with median particle size of 17.09 µm at 75 °C air outlet temperature and 19.19 µm at 85 °C air outlet temperature for cow's skim milk powders. Ogolla et al.^[22] have reported that an increase in inlet air temperature and a decrease in milk flow rate caused the formation of smaller particles. However, the effect of drying temperature was different in our study. This difference could be attributed to the fact that a higher drying

temperature accelerates the drying rate of droplets, promoting the fast formation of a crust at their surface, and therefore limit shrinkage, which leads to larger particles.^[46]

The span showed small significant differences between all spray-dried milk powders. However, there is no marked effect of either the milk type or the spray-drying conditions on the span. Indeed, for skim dromedary milk powders, the increase in the air outlet temperature resulted in a slight decrease in the span values from 1.93 to 1.76. For skim cow's milk powders, span values were about 1.75 and 1.81 at 75 and 85 °C air outlet temperature, respectively.

Color of skim dromedary and cow's milk powders

Table 4 displays the color parameters of skim dromedary and cow's milk powders. Whatever the spray-drying conditions and the milk type, the produced powders were very bright (L^* was elevated), had a low color saturation (C^* was very low), and their main color was green-yellow (owing to H° values). Hence, spray-dried powders appeared relatively white, as such a lowly-saturated color cannot be detected by the human eye at this high level of brightness. Skim cow's milk powders were significantly yellower than skim dromedary milk powders whatever the spray-drying conditions. ~~This could probably be due to the higher residual fat content in skim cow's milk powders.~~ This could probably be attributed to the lower content in β -carotene of skim dromedary milk powders compared to skim cow's milk powders.^[47,48]

Although spray-drying at higher air temperature seemed not to affect brightness and main color, it slightly increased color saturation, which could contribute to the promotion of consumer acceptability of these powders. This increase in powder color saturation may be related to the Maillard reaction susceptible to occur between milk proteins and lactose, known to be enhanced at higher temperature.^[34,49,50] These findings could also be attributed to the lower moisture content of powders spray-dried at higher temperatures.^[22] Similar results were

previously obtained by Ogolla et al.^[22] and Sulieman et al.^[18] who investigated the effect of the inlet air temperatures on the color of spray-dried dromedary milk powders. These authors reported that higher inlet drying air temperatures resulted in decreased L* and hue angles while increasing the a*, b* and chroma values of spray-dried dromedary milk powders.

Morphology and surface appearance of skim dromedary and cow's milk powders

The scanning electron micrographs of skim dromedary and cow's milk powders are presented in Figure 3. Whatever the spray-drying conditions and the milk type, spray-dried powders appeared as agglomerates of small particles rather than single particles. Small agglomerates with angular and homogeneous shape are visible in Figure 3. Furthermore, the particles had a shriveled appearance as well as an irregular and rough surface, which is the classical shape of skim milk powders. Few pores could be detected at their surface, as pointed out by arrows in Figure 3 D2 f and C2 f. Habtegebriel et al.^[16] reported that, independently of spray-drying conditions, whole dromedary milk powders had a smooth surface, covered by a fat layer, whereas skim dromedary milk powders presented a rougher surface. Similar results were reported by other researchers^[23,31] which showed that skim cow's milk powders are composed of flat, wrinkled, and collapsed particles. Furthermore, it has been shown that the presence of surface fat makes particles sticky, enhancing their tendency to form agglomerates.^[31] This may be the case in our study given the significant fat content of skim dromedary and cow's milk powders probably leading to a high proportion of surface covered by fat^[38] and the presence of numerous agglomerates evidenced by SEM images. Habtegebriel et al.^[16] added that the presence of pores at the particle surface might facilitate water diffusion into the powder, thus enhancing its rehydration ability. Few pores were observable at the surface of particles spray-dried in our study, probably due to the presence of fat, which may be related to the hypothesized stickiness of particles. Furthermore, at higher air outlet temperature, particle

agglomerates seemed to be denser and the particles appeared more tightly bound (Figure 3: D2e and C2e).

Rehydration ability of skim dromedary and cow's milk powders

The reconstitution properties of skim dromedary and cow's milk powders are presented in Table 4. All spray-dried powders could be considered as non-wettable, as their wettability time was higher than 120 s.^[51] This poor wettability can mainly be attributed to the fineness of powders produced with the combination of pilot spray-dryer and bi-fluid nozzle employed in this study.^[39] In fact, the larger the particle, the higher its weight, and thus the more easily the particle can overcome water surface tension and immerse in water. It has been reported in the literature that a median particle size over 200 µm promotes powder wetting.^[52] Moreover, it has previously been reported that large particles are more prone to have large surface pores, which results in fast wetting.^[38] According to Gaiani et al.^[41], the wetting step mainly depends on particle surface charge, surface activity, size, porosity, surface composition (especially, proportion of hydrophilic compounds), contact angle between the powder bed and water, and powder density. Besides, the poor wettability of dairy powders has also often been attributed to the presence of various hydrophobic compounds (lipids, caseins, etc.) at the particle surface.^[38] Kim et al.^[38] reported a wetting time over 15 min for whole milk powder. Spray-dried powders produced in the current study had a non-negligible fat content, which can lead to a large fraction of the surface covered by lipids and explain their poor wettability.

Moreover, all investigated spray-dried powders could be considered as hardly dispersible. Indeed, their dispersibility indices were well lower than 95 %.^[51] Spray-drying conditions had an opposite effect on the rehydration behavior of the two types of milk powders. It is evident from Table 4 that dispersibility was positively correlated with the air outlet temperature for skim dromedary milk powder. Actually, the dispersibility index increased from

34.84 % at 75 °C air outlet temperature to 41.82 % at 85 °C air outlet temperature. Concerning the air outlet temperature, it had no significant difference on dispersibility indices of skim cow's milk powders. These results could also be attributed to granulometric characteristics of skim dromedary and cow's milk powders. In fact, and generally, the larger the mean particle size, the higher the dispersibility index.^[53] According to Chever et al.^[29], a rapid dispersion requires particle sizes in the range from 150 to 200 µm, which is not the case in our study. However, for powders produced in the present study, dispersibility and median particle size were highly positively correlated (Pearson's correlation coefficient of 0.89), in agreement with the literature^[53]. The higher fat content of cow's milk probably led to the formation of stickier particles, thus more difficult to disperse due to the presence of more interparticular interactions.

In general, milk powders are considered to be soluble if their solubility index is higher than 99 %.^[51] Solubility is known to be mainly affected by powder composition, especially by the nature and structure of proteins.^[54] Skim dromedary and cow's milk powders produced in our study could be considered as fairly soluble, as their solubility indices ranged between 78.31 and 95.26 %. Besides, the spray-drying conditions did not have the same effect on the rehydration properties depending on the milk type. On one hand, skim dromedary milk powder produced at 85 °C air outlet temperature showed a significantly higher solubility index (95.26 %) than the same powder spray-dried at 85 °C outlet air temperature (91.95 %). On the other hand, skim cow's milk powder revealed significantly higher solubility when spray-dried at 75 °C outlet air temperature. These results could be related to the significant lower fat content of skim dromedary milk powders and the difference in particle size distributions of studied powders. Indeed, Pearson's correlation coefficient between solubility and median particle size was 0.66, indicating a medium positive correlation. Besides, whatever the spray-drying conditions, dromedary skim milk powders had slightly better rehydration properties, which could also be related to the sensitivity of cow's proteins to thermal denaturation. In fact, it has

been reported that spray-drying of whole dromedary milk did not cause any noticeable damage to its protein fraction, resulting in a higher solubility of dromedary milk powder than cow's milk powder.^[55] Additionally, Anandharamakrishnan et al.^[56] reported that increasing the outlet air temperatures causes partial protein denaturation and subsequent protein aggregation, inducing solubility loss, as observed for cow's milk powders produced in the present work. From these results, it can be concluded that increasing air outlet temperature did not improve the rehydration characteristics of dromedary and cow's skim milk powders, as rehydration mainly depends on particle size, which was very little affected when changing the outlet air temperature.

CONCLUSION

This study pointed out that spray-drying is a good technique to stabilize dromedary milk and postpone its use. Spray-drying conditions have a noticeable effect on powder physicochemical properties and rehydration ability. In this study, skim dromedary and cow's milks were spray-dried without prior concentration to avoid introducing another source of process variability. The findings indicated that the outlet drying air temperatures significantly influenced the physical and rehydration properties of obtained powders. Overall, applying an air outlet temperature of 85 °C led to better chemical and physical properties for both milk powders. Indeed, a higher air outlet temperature (85 °C) resulted in higher spray-drying yields and skim dromedary and cow's milk powders with higher total solid contents and lower water activity, which is favorable for preservation purposes. When increasing the air outlet temperature, skim dromedary and cow's milk powders presented higher median particle sizes. Spray-drying at 85 °C outlet temperature seemed not to affect powder brightness and main color, but it slightly increased color saturation. The results of the present study revealed that regardless of process conditions and milk type, skim milk powders spray-dried at pilot scale could be considered as non-wettable, hardly dispersible, and fairly soluble. However, slightly

better rehydration properties were obtained for dromedary skim milk powders spray-dried at 85 °C outlet air temperature. The SEM analysis showed that spray-dried skim milk powders were composed of agglomerates of small particles with angular and homogeneous shapes. This could be detrimental to their flow properties and may result in handling issues when conveying or storing these powders. Therefore, it will be interesting in further research works to investigate the flow properties of skim dromedary and cow's milk powders spray-dried at pilot scale.

DISCLOSURE STATEMENT

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REFERENCES

- [1] Al-Haj, O.A.; Al-Kanhal, H.A. Compositional, Technological and Nutritional Aspects of Dromedary Camel Milk, *Int. Dairy J.* 2010, 20, 811–821. <https://doi.org/10.1016/j.idairyj.2010.04.003>
- [2] Shamsia, S.M. Nutritional and therapeutic properties of camel and human milks, *Int. J. Genet. Mol. Biol.* 2009, 1, 52–58. <http://www.academicjournals.org/IJGMB>
- [3] El-Agamy, E.I. Effect of heat treatment on camel milk proteins with respect to antimicrobial factors: a comparison with cow's and buffalo milk proteins, *Food Chem.* 2000, 68, 227–232. [https://doi.org/10.1016/S0308-8146\(99\)00199-5](https://doi.org/10.1016/S0308-8146(99)00199-5)
- [4] Felfoul, I.; Lopez, C.; Gaucheron, F.; Attia, H.; Ayadi, M.A. Fouling behavior of camel and cow milks under different heat treatments, *Food Bioprocess Tech.* 2015, 8, 1771 - 1778. <https://doi.org/10.1007/s11947-015-1529-5>
- [5] Felfoul, I.; Beaucher, E.; Cauty, C.; Attia, H.; Gaucheron, F.; Ayadi, M.A. Deposit Generation During Camel and Cow Milk Heating: Microstructure and Chemical Composition, *Food Bioprocess Tech.* 2016, 9, 1268 - 1275. <https://doi.org/10.1007/s11947-016-1714-1>
- [6] Attia, H.; Kherouatou, N.; Fakhfakh, N.; Khorchani, T.; Trigui, N. Dromedary Milk Fat: Biochemical, Microscopic and Rheological Characteristics, *J. Food Lipids.* 2000, 7, 95–112. <https://doi.org/10.1111/j.1745-4522.2000.tb00164.x>
- [7] Hailu, Y.; Hansen, E.B.; Seifu, E.; Eshetu, M.; Petersen, M.A.; Lametsch, R.; Rattray, F.; Ipsen, R. Rheological and sensory properties and aroma compounds formed during ripening of soft brined cheese made from camel milk, *Int. Dairy J.* 2018, 81, 122–130. <https://doi.org/10.1016/j.idairyj.2018.01.007>
- [8] Berhe, T.; Seifu, E.; Kurtu, M.Y. Physicochemical properties of butter made from camel milk, *Int. Dairy J.* 2013, 31, 51–54. <https://doi.org/10.1016/j.idairyj.2013.02.008>

- [9] Mudgil, P.; Jumah, B.; Ahmad, M.; Hamed, F.; Maqsood, S. Rheological, micro-structural and sensorial properties of camel milk yogurt as influenced by gelatin, LWT- Food Sci. Technol. 2018, 98, 646-653. <https://doi.org/10.1016/j.lwt.2018.09.008>
- [10] Kilcast, D.; Subramaniam, P. Food and Beverage Stability and Shelf Life. 1st Edn., Woodhead Publishing, Cambridge, UK., ISBN-13: 978-1845697013, 2011, 864. <https://www.worldcat.org/title/food-and-beverage-stability-and-shelf-life/oclc/866858740>
- [11] Schuck, P.; Jeantet, R.; Dolivet, A. Analytical Methods for Food and Dairy Powders; John Wiley & Sons: Oxford (2012). <https://onlinelibrary.wiley.com/doi/book/10.1002/9781118307397>
- [12] Jangam, S. V. An Overview of Recent Developments and Some R&D Challenges Related to Drying of Foods. Dry. Technol. 2011, 29, 1343–1357. DOI: [10.1080/07373937.2011.594378](https://doi.org/10.1080/07373937.2011.594378).
- [13] Birchal, V. S.; Huang, L.; Mujumdar, A. S.; Passos, M. L. Spray Dryers: Modeling and Simulation. Dry. Technol. 2006, 24, 359–371. DOI: [10.1080/07373930600564431](https://doi.org/10.1080/07373930600564431).
- [14] Bellinghausen, R. Spray Drying from Yesterday to Tomorrow: An Industrial Perspective. Dry. Technol. 2019, 37, 612–622. DOI: [10.1080/07373937.2018.1517778](https://doi.org/10.1080/07373937.2018.1517778).
- [15] Schuck, P.; Jeantet, R.; Bhandari, B.; Chen, X.D.; Perrone, I.T.; de Carvalho, A.F.; Fenelon, M.; Kelly, P. Recent advances in spray drying relevant to the dairy industry: A comprehensive critical review, Dry. Technol. 2016, 34, 1773-1790. DOI: [10.1080/07373937.2016.1233114](https://doi.org/10.1080/07373937.2016.1233114)
- [16] Habtegebriel, H.; Edward, D.; Wawire, M.; Sila, D.; Seifu, E. Effect of operating parameters on the surface and physico-chemical properties of spray-dried camel milk powders, Food Bioprod. Process. 2018, 112, 137 - 149. <https://doi.org/10.1016/j.fbp.2018.09.010>

- [17] Rahman, M.S.; Al-Hakmani, H.; Al-Alawi, A.; Al-Marhubi, I. Thermal characteristics of freeze-dried camel milk and its major components, *Thermochim. Acta.* 2012, 549, 116–123. <https://doi.org/10.1016/j.tca.2012.09.005>
- [18] Sulieman, A.M.E.; Elamin, O.M.; Elkhailifa, E.A.; Laleye, L. Comparison of Physicochemical Properties of Spray-Dried Camel's Milk and Cow's Milk Powder, *Int. J. Food Sci. Nutr. Eng.* 2014, 4, 15–19. DOI: [10.5923/j.food.20140401.03](https://doi.org/10.5923/j.food.20140401.03)
- [19] Smits, M.G.; Huppertz, T.; Alting, A.C.; Kiers, J. Composition, constituents and properties of Dutch camel milk, *J. camel pract. Res.* 2011, 18, 1–6. <https://www.milkessence.nl/wp-content/uploads/2018/04/Dutch-camel-080411-opm-NIZO.pdf>
- [20] Zouari, A.; Perrone, I.T.; Dolivet, A.; Schuck, P.; Gaucheron, F.; Attia, H.; Ayadi, M.A. Physicochemical properties of spray dried camel milk powder: a comparative study with cow milk powder, *EuroDrying'2017 – 6th European Drying Conference-Liège, Belgium*, 2017, 19-21 June 2017. <https://hal.archives-ouvertes.fr/hal-01546433>
- [21] Zouari, A.; Perrone, I.T.; Schuck, P.; Gaucheron, F.; Dolivet, A.; Attia, H.; Ayadi, M.A. Effect of outlet drying temperature and milk fat content on the physicochemical characteristics of spray-dried camel milk powder, *Dry. Technol.* 2019, 37, 1615-1624. DOI: [10.1080/07373937.2018.1526189](https://doi.org/10.1080/07373937.2018.1526189).
- [22] Ogolla, J.A.; Kulig, B.; Bădulescu, L.; Okoth, M.W.; Esper, G.; Breitenbach, J.; Hensel, O.; Sturm, B. Influence of Inlet Drying Air Temperature and Milk Flow Rate on the Physical, Optical and Thermal Properties of Spray-Dried Camel Milk Powders, *Food Bioprocess Technol.* 2019, 12, 751-768. <https://doi.org/10.1007/s11947-019-2243-5>
- [23] Kelly, G.M.; O'Mahony, J.A.; Kelly, A.L.; Huppertz, T.; Kennedy, D.; O'Callaghan, D.J. Influence of protein concentration on surface composition and physico-chemical properties

- of spray-dried milk protein concentrate powders, *Int. Dairy J.* 2015, 51, 34–40.
<https://doi.org/10.1016/j.idairyj.2015.07.001>
- [24] A.O.A.C, Official methods of analysis of AOAC International (20th ed.). Rockville, Maryland, USA: AOAC international, 2016.
- [25] Folch, J.; Lees, M.; Sioane-Stanley, G.A. A simple method for isolation and purification of total lipids from animal tissues, *J. Biol. Chem.* 1957, 266, 497 - 509.
<https://www.ncbi.nlm.nih.gov/pubmed/13428781>
- [26] Saricoban, C.; Yilmaz, M.T.; Modelling the Effects of Processing Factors on the Changes in Colour Parameters of Cooked Meatballs Using Response Surface Methodology, *World App. Sci. J.* 2010, 9, 14-22. [http://www.idosi.org/wasj/wasj9\(1\)/2.pdf](http://www.idosi.org/wasj/wasj9(1)/2.pdf)
- [27] ISO, Lait sec et produits laitiers en poudre – Détermination de l'indice d'insolubilité. Norme ISO 8156, 2005. <https://www.iso.org/fr/standard/42069.html>
- [28] FIL, Poudres de lait instantanées – Détermination de la dispersibilité et de la mouillabilité. Norme FIL 87, 1979. <https://www.iso.org/fr/standard/60474.html>
- [29] Chever, S.; Méjean, S.; Dolivet, A.; Mei, F.; Den Boer, C.M.; Le Barzic, G.; Jeantet, R.; Schuck, P. Agglomeration during spray drying: Physical and rehydration properties of whole milk/sugar mixture powders, *LWT - Food Sci Technol.* 2017, 83, 33 - 41.
<https://doi.org/10.1016/j.lwt.2017.05.002>
- [30] Nijdam, J. J., Langrish, T. A. G. An investigation of milk powders produced by a laboratory-scale spray dryer. *Dry. Technol.* 2005, 23, 1043–1056.
<https://doi.org/10.1081/DRT200060208>.
- [31] Langrish, T.A.G.; Marquez, N.; Kota, K. An Investigation and Quantitative Assessment of Particle Shape in Milk Powders from a Laboratory-Scale Spray Dryer, *Dry. Technol.* 2006, 24, 1619–1630. <https://doi.org/10.1080/07373930601031133>

- [32] de Oliveira, A.H.; Cavalcanti Mata, M.E.R.M.; Fortes, M.; Martins Duarte, M.E.; Pasquali, M.; Lisboa, H.M. Influence of spray drying conditions on the properties of whole goat milk, *Dry. Technol.* 2020, 1-12, <https://doi.org/10.1080/07373937.2020.1714647>
- [33] Deeth, H.C.; Hartanto, J. Chemistry of Milk – Role of Constituents in Evaporation and Drying, 2006, 1–27. <https://doi.org/10.1002/9781444322729.ch1>
- [34] Roos, Y.H. Water activity and glass transition. In G. V. Barbosa-Canovas, A. J. Fontana, Jr., S. J. Schmidt, T. P. Labuza (Eds.), *Water activity in foods: Fundamentals and applications* (pp. 29-45). Oxford, UK: Blackwell Publishing, 2007. <https://doi.org/10.1002/9780470376454.ch3>
- [35] Petit, J.; Méjean, S.; Accart, P.; Galet, L.; Schuck, P.; Le Floch-Fouéré, C.; Delaplace, G.; Jeantet, R. A dimensional analysis approach for modelling the size of droplets formed by bi-fluid atomisation, *J. Food Eng.* 2015, 149, 237 - 247. <https://doi.org/10.1016/j.jfoodeng.2014.10.022>
- [36] Normand, V.; Subramaniam, A.; Donnelly, J.; Bouquerand, P.-E. Spray drying thermodynamics and operating conditions, *Carbohydr. Polym.* 2013, 97, 489-495. <https://doi.org/10.1016/j.carbpol.2013.04.096>
- [37] Gallo, L.; Ramírez-Rigo, M.V.; Piña, J.; Bucalá, V. A comparative study of spray-dried medicinal plant aqueous extracts. Drying performance and product quality, *Chem. Eng. Res. Des.* 2015, 104, 681-694. <https://doi.org/10.1016/j.cherd.2015.10.009>
- [38] Kim, E.H.J.; Chen, X.D.; Pearce, D. Surface characterization of four industrial spray-dried dairy powders in relation to chemical composition, structure and wetting property, *Colloids Surf. B.* 2002, 26, 197–212. [https://doi.org/10.1016/S0927-7765\(01\)00334-4](https://doi.org/10.1016/S0927-7765(01)00334-4)
- [39] Guerin, J.; Petit, J.; Burgain, J.; Borges, F.; Bhandari, B.; Perroud, C.; Desobry, S.; Scher, J.; Gaiani, C. Lactobacillus rhamnosus GG encapsulation by spray-drying : Milk proteins

- 630 clotting control to produce innovative matrices, *J. Food Eng.* 2017, 193, 10 - 19.
- 631 <https://doi.org/10.1016/j.jfoodeng.2016.08.008>
- 632 [40] Khanji, A.N.; Michaux, F.; Petit, J.; Salameh, C.; Rizk, T.; Jasniewski, J.; Banon, S.
- 633 Structure, gelation, and antioxidant properties of curcumin-doped casein micelle powder
- 634 produced by spray-drying, *Food Funct.* 2018, 9, 971 - 981.
- 635 <https://pubs.rsc.org/en/content/articlelanding/2018/fo/c7fo01923>
- 636 [41] Gaiani, C.; Ehrhardt, J.J.; Scher, J.; Hardy, J.; Desobry, S.; Banon, S. Surface
- 637 composition of dairy powders observed by X-ray photoelectron spectroscopy and effects on
- 638 their rehydration properties, *Colloids Surf. B.* 2006, 49, 71 - 78.
- 639 <https://doi.org/10.1016/j.colsurfb.2006.02.015>
- 640 [42] Nikolova, Y.; Petit, J.; Sanders, C.; Gianfrancesco, A.; Desbenoit, N.; Frache, G.;
- 641 Francius, G.; Scher, J.; Gaiani, C. Is it possible to modulate the structure of skim milk particle
- 642 through drying process and parameters? *J. Food Eng.* 2014, 142, 179 - 189.
- 643 <https://doi.org/10.1016/j.jfoodeng.2014.05.026>
- 644 [43] Nikolova, Y.; Petit, J.; Gianfrancesco, A.; Sanders, C. F. W.; Scher, J.; Gaiani, C. Impact
- 645 of Spray Drying Process Parameters on Dairy Powder Surface Composition and Properties.
- 646 *Dry. Technol.* 2015a, 33, 1654–1661. DOI: [10.1080/07373937.2015.1060494](https://doi.org/10.1080/07373937.2015.1060494).
- 647 [44] Nikolova, Y.; Petit, J.; Sanders, C.; Gianfrancesco, A.; Scher, J.; Gaiani, C. Toward a
- 648 better determination of dairy powders surface composition through XPS matrices development,
- 649 *Colloids Surf. B.* 2015b, 125, 12 - 20. <https://doi.org/10.1016/j.colsurfb.2014.11.009>
- 650 [45] Fournaise, T.; Burgain, J.; Perroud, C.; Scher, J.; Gaiani, C.; Petit, J. Impact of
- 651 formulation on reconstitution and flowability of spray-dried milk powders, *Powder Technol.*
- 652 2019. <https://doi.org/10.1016/j.powtec.2020.05.085>

- [46] Kim, E. H.-J.; Chen, X. D.; Pearce, D. Surface Composition of Industrial Spray-Dried Milk Powders. 2. Effects of Spray Drying Conditions on the Surface Composition. *J. Food Eng.* 2009, 94, 169–181. DOI: 10.1016/j.jfoodeng.2008.10.020.
- [47] Abu-Lehia, I. H. ; Al-Mohizea, I. S. ; El-Behry, M. Studies on the production of ice cream from camel milk products. *Aust. J. Dairy Technol.* 1989, 44, 31–34. <https://core.ac.uk/display/60946451>
- [48] Farah, Z.; Rettenmaier, R.; Atkins, D. Vitamin content in camel milk. *Int. J. Vitam. Nutr. Res.* 1992, 62, 30-33. <https://www.ncbi.nlm.nih.gov/pubmed/1587705>
- [49] Gaiani, C. Etude des mécanismes de réhydratation des poudres laitières [Ressource électronique] : influence de la structure et de la composition des poudres. Mémoire de thèse de doctorat soutenu le 5 juillet 2006. S.1. : Vandoeuvre-les-Nancy : INPL, 2006. <https://hal.univ-lorraine.fr/tel-01752477>
- [50] Sturm, B., Hofacker, W., & Hensel, O. (2012). Optimizing the drying parameters for hot air-dried apples. *Dry. Technol.* 2012, 30, 1570–1582. <https://doi.org/10.1080/07373937.2012.698439>.
- [51] Haugaard Sorensen, I.; Ktag, J.; Pisecky, J.; Westergaard, V. *Méthodes d'analyses des produits laitiers déshydratés*. Niro Atomizer, Copenhagen, Danemark, 1978.
- [52] Szulc, K.; Lenart, A. Water vapour adsorption properties of agglomerated baby food powders, *J. Food Eng.* 2012, 109, 135-141. <https://doi.org/10.1016/j.jfoodeng.2011.09.023>
- [53] Börjesson, E.; Innings, F.; Trägårdh, C.; Bergenståhl, B.; Paulsson, M. Evaluation of particle measures relevant for powder bed porosity - A study of spray dried dairy powders, *Powder Technol.* 2014, 253, 453–463. <https://doi.org/10.1016/j.powtec.2013.11.050>
- [54] Himmetagaoglu, A.B.; Erbay, Z. Effects of spray drying process conditions on the quality properties of microencapsulated cream powder, *Int. Dairy J.* 2018, 88, 60 - 70. <https://doi.org/10.1016/j.idairyj.2018.08.004>

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2
3 678 [55] Smits, M.G.; Huppertz, T.; Alting, A.C.; Kiers, J. Composition, constituents and
4
5 679 properties of Dutch camel milk. J. Camel Pract. Res. 2011, 18, 1–6.
6
7 680 <https://www.milkessence.nl/wp-content/uploads/2018/04/Dutch-camel-080411-opm->
8
9 681 [NIZO.pdf](#)
10
11 682 [56] Anandharamakrishnan, C., Rielly, C. D., Stapley, A. G. F. Effects of Process Variables
12
13 683 on the Denaturation of Whey Proteins during Spray Drying. Dry. Technol. 2007, 25, 799–
14
15 684 807. [doi:10.1080/07373930701370175](https://doi.org/10.1080/07373930701370175)
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685 **Figure captions**

686 **Figure 1.** Schema (A) and dimensions (B) of the Micra Spray MS 150 single-effect spray tower.

687 **Figure 2.** Particle size distributions of skim dromedary and cow's milk powders.

688 **Figure 3.** Scanning electron micrographs of skim dromedary and cow's milk powders. D1:

689 Dromedary_C1; D2: Dromedary_C2; C1: Cow_C1; C2: Cow_C2. Magnifications: $200 \times$ (a),

690 $600 \times$ (b), $2\,000 \times$ (c), $4\,000 \times$ (d), $10\,000 \times$ (e), and $45\,000 \times$ (f).

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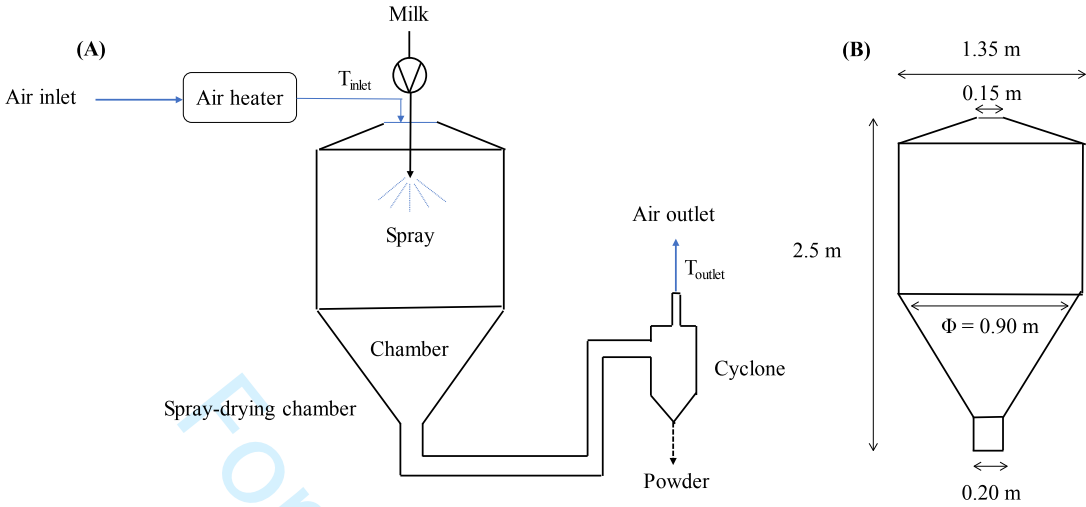


Figure 1

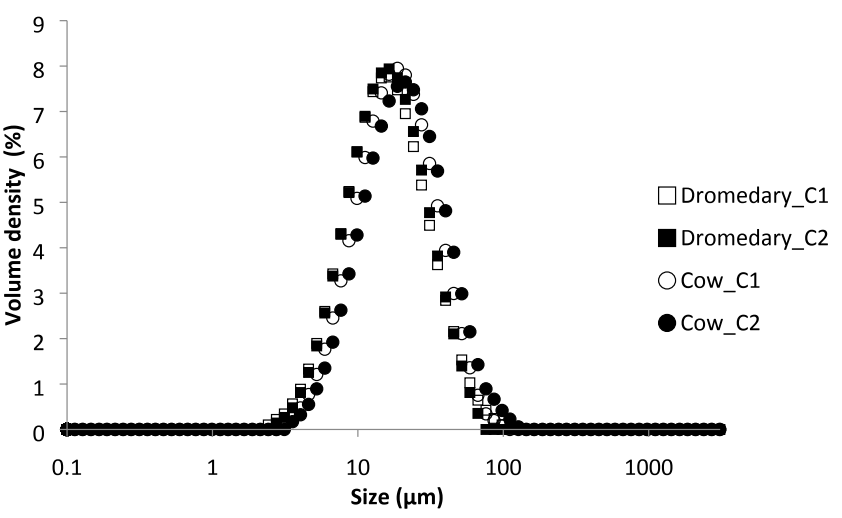


Figure 2

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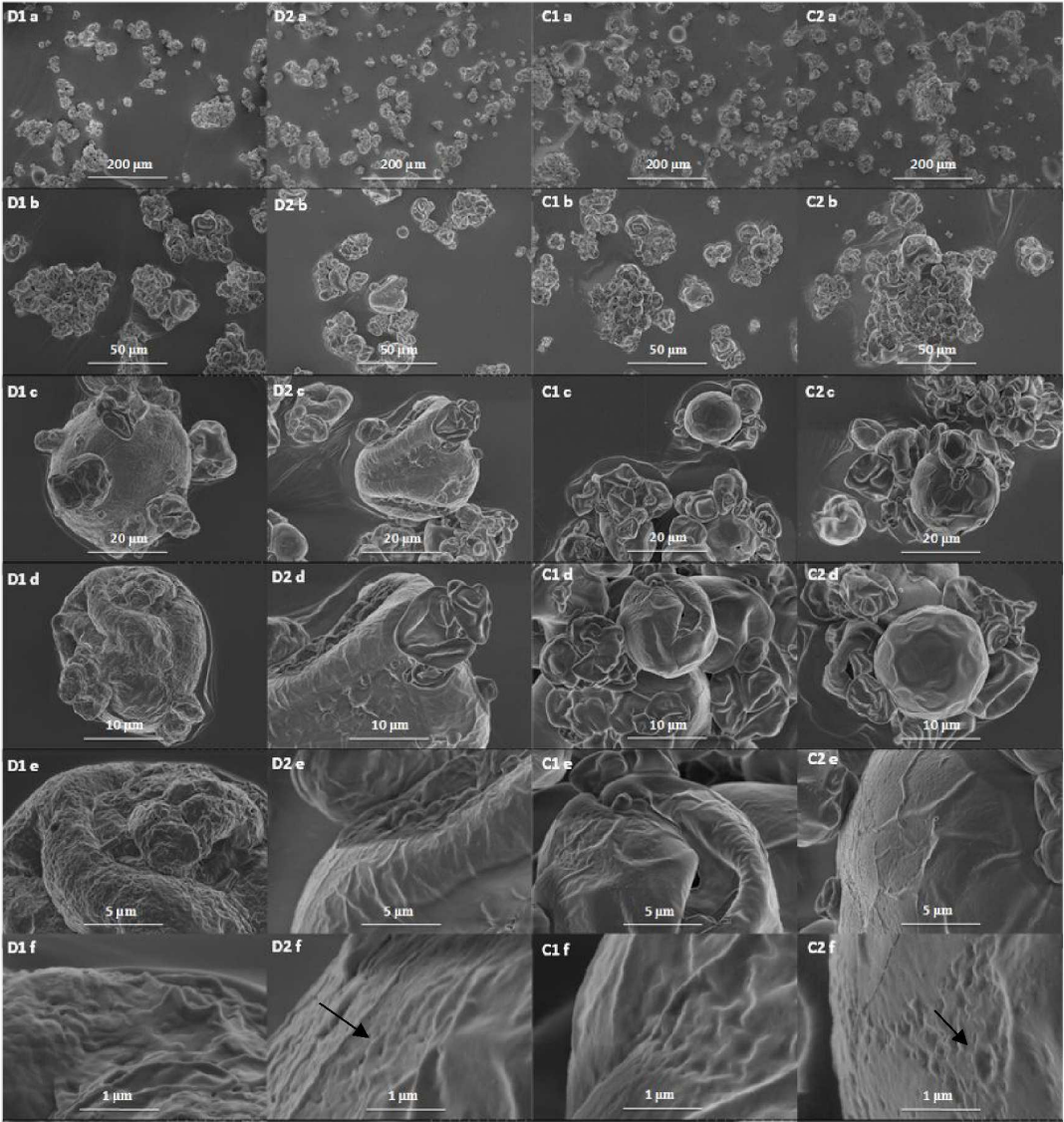


Figure 3

Table 1. Spray-drying conditions used for the production of skim dromedary and cow's milk powders.

Powder	sample	Air inlet	Air outlet	Feed flow rate
acronym		temperature	temperature	(mL.min ⁻¹)
		(°C)	(°C)	
Dromedary_C1		230.0 ± 1.3	74.5 ± 0.7	74.7 ± 2.1
Cow_C1		230.4 ± 1.6	74.4 ± 0.9	76.5 ± 2.2
Dromedary_C2		230.3 ± 1.8	84.3 ± 1.1	65.4 ± 3.7
Cow_C2		230.6 ± 1.3	84.8 ± 0.8	69.5 ± 2.9

Table 2. Proximate composition and dynamic viscosity of skim dromedary and cow's milks.

	Skim dromedary milk	Skim cow's milk
Total solids (%(w/w) on wet basis)	9.52 ± 0.51 ^a	12.05 ± 0.29 ^b
Proteins (%(w/w) on dry basis)	32.88 ± 1.97 ^a	29.46 ± 2.70 ^b
Fat (%(w/w) on dry basis)	7.35 ± 0.09 ^a	10.04 ± 0.13 ^b
Ash (%(w/w) on dry basis)	8.93 ± 0.04 ^a	6.64 ± 0.09 ^b
Carbohydrates (%(w/w) on dry basis)	50.84 ± 0.02 ^a	53.86 ± 0.05 ^b
Dynamic viscosity (mPa.s)	2.96 ± 0.13 ^a	3.89 ± 0.12 ^b

Means with different superscripted letters in the same row were significantly different according to Tukey's HSD test ($p < 0.05$).

Table 3. Proximate composition, water activity, and spray-drying yield of skim dromedary and cow's milk powders produced in the two spray-drying assays.

	Dromedary_C1	Dromedary_C2	Cow_C1	Cow_C2
Total solids (%(w/w) on wet basis)	92.96 ± 0.33 ^c	97.01 ± 0.16 ^a	94.44 ± 0.12 ^b	96.63 ± 0.08 ^a
Proteins (%(w/w) on dry basis)	22.50 ± 2.48 ^a	23.71 ± 0.90 ^a	25.73 ± 2.24 ^a	27.00 ± 2.38 ^a
Fat (%(w/w) on dry basis)	12.20 ± 0.47 ^b	12.33 ± 1.89 ^b	16.35 ± 1.00 ^a	15.89 ± 0.68 ^a
Ash (%(w/w) on dry basis)	10.74 ± 0.38 ^a	8.90 ± 0.18 ^b	6.63 ± 0.23 ^c	6.41 ± 0.34 ^c
Carbohydrates (%(w/w) on dry basis)	53.74 ± 2.07 ^{ab}	55.66 ± 0.21 ^a	51.31 ± 2.62 ^b	50.71 ± 0.15 ^{ab}
Water activity (-)	0.391 ± 0.002 ^a	0.203 ± 0.003 ^d	0.385 ± 0.002 ^b	0.274 ± 0.002 ^c
Spray-drying yield (%)	19.81	51.26	25.51	31.09

Means with different superscripted letters in the same row were significantly different according to Tukey's HSD test ($p < 0.05$).

Table 4. Granulometric characteristics, color and rehydration properties of skim dromedary and cow's milk powders.

	Dromedary_C1	Dromedary_C2	Cow_C1	Cow_C2
Granulometric characteristics				
D ₁₀ (μm)	6.41 ± 0.06 ^b	6.55 ± 0.10 ^a	7.54 ± 0.06 ^c	8.28 ± 0.03 ^d
D ₅₀ (μm)	14.83 ± 0.08 ^a	14.84 ± 0.21 ^a	17.09 ± 0.18 ^b	19.19 ± 0.10 ^c
D ₉₀ (μm)	35.09 ± 0.36 ^c	32.68 ± 0.34 ^b	37.43 ± 0.50 ^a	43.04 ± 0.33 ^d
Span (-)	1.93 ± 0.02 ^b	1.76 ± 0.01 ^a	1.75 ± 0.01 ^a	1.81 ± 0.01 ^b
Color properties				
L* (-)	94.11 ± 0.01 ^a	95.05 ± 0.10 ^c	94.30 ± 0.0 ^b	94.31 ± 0.01 ^b
a* (-)	-1.42 ± 0.01 ^a	-2.01 ± 0.03 ^b	-2.18 ± 0.02 ^d	-2.11 ± 0.04 ^c
b* (-)	7.57 ± 0.01 ^d	8.87 ± 0.02 ^c	10.10 ± 0.01 ^b	10.40 ± 0.01 ^a
C* (-)	7.70 ± 0.01 ^d	9.10 ± 0.03 ^c	10.33 ± 0.01 ^b	10.61 ± 0.01 ^a
H (°)	100.63 ± 0.07 ^a	102.78 ± 0.13 ^d	102.17 ± 0.08 ^c	101.45 ± 0.19 ^b
Rehydration properties				
Wetting time (s)	> 1 800	> 1 800	> 1 800	> 1 800
Dispersibility index (%)	34.84 ± 1.69 ^b	41.82 ± 1.88 ^a	20.71 ± 0.52 ^c	19.35 ± 1.13 ^c
Solubility index (%)	91.95 ± 0.36 ^b	95.26 ± 0.87 ^a	88.00 ± 0.36 ^c	78.31 ± 2.64 ^d

Means with different superscripted letters in the same row were significantly different according to Tukey's HSD test ($p < 0.05$).