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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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3 1 **Impact of spray-drying conditions on physicochemical properties and**
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6 2 **rehydration ability of skim dromedary and cow's milk powders**
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3 16 **ABSTRACT**
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5 17 The effect of spray-drying conditions on physicochemical and rehydration ability of
6 18 skim dromedary and cow's milk powders was evaluated. Two sets of spray-drying conditions
7 19 were applied on skim dromedary and cow's milks to determine the effect of air outlet
8 20 temperature (75 and 85 °C) and milk type on proximate composition, water activity, particle
9 21 size distribution, color, and rehydration ability of spray-dried powders. While the water activity
10 22 of powders was close to 0.4 for a production at 75 °C air outlet temperature, it ranged from 0.2
11 23 to 0.3 for a production at 85 °C air outlet temperature. Skim dromedary milk powder had a
12 24 lower water activity than skim cow's milk powder after spray-drying at 85 °C air outlet
13 25 temperature. The particle size distributions of spray-dried skim milk powders were centered
14 26 around 14 - 20 µm. The particles of skim dromedary milk powders were smaller than those of
15 27 skim cow's milk powders as skim dromedary milk was less viscous, leading to smaller sprayed
16 28 droplets. Whatever the spray-drying conditions and the milk type, the produced powders were
17 29 very bright and had a low color saturation. Scanning electron microscopy images showed that
18 30 spray-dried powders appeared as agglomerates of small particles with angular shapes rather
19 31 than individual particles. All investigated spray-dried powders were considered non-wettable,
20 32 hardly dispersible, and fairly soluble. These results demonstrated that the outlet drying air
21 33 temperature significantly influenced the physical and rehydration properties of spray-dried
22 34 dairy powders.
23 35

24 36 **Keywords:** spray-drying; dromedary milk; water activity; particle size distribution; rehydration
25 37 ability; SEM
26 38

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]

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3 63 However, to the best of our knowledge, only few studies have investigated the impact
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5 64 of spray-drying on dromedary milk properties.^[17,18] Smits et al.^[19] have shown that spray-drying
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8 65 of raw whole dromedary milk did not cause any noticeable damage to its protein fraction and
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10 66 dromedary milk powder had a higher solubility than cow's milk powder. Similarly, Zouari et
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12 67 al.^[20] have reported that the spray-drying process induces a mild heat treatment, preserving the
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14 68 protein quality of dromedary and cow's milks.

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17 69 Most of these studies have focused on the evaluation of the physicochemical properties
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19 70 of dromedary milk powders. The number of studies about the influence of spray-drying
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21 71 conditions is very limited. In fact, Zouari et al.^[21] studied the effect of air outlet temperature
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23 72 and milk fat content on the physicochemical characteristics of spray-dried dromedary milk
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25 73 powder. Recently, Habtegebriel et al.^[16] investigated the effect of pretreatments of the feed
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27 74 concentrate prior to spray-drying on cyclone recovery and the physicochemical properties of
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29 75 dromedary milk powders. These authors reported that operating at less severe processing
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31 76 temperature during spray-drying is necessary to retain higher solubility of dromedary milk
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33 77 proteins. They also showed that dromedary milk powders had higher bulk densities than cow's
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35 78 milk powders processed under similar drying conditions. Furthermore, Ogolla et. al.^[22] studied
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37 79 the influence of inlet drying air temperature and milk flow rate on the physical, optical, and
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39 80 thermal properties of spray-dried dromedary milk powders. They reported that the inlet drying
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41 81 air temperatures significantly influenced moisture content and the color properties of the
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43 82 powders. Indeed, with the increase in inlet drying air temperatures and a decrease in milk flow
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45 83 rate, the moisture content and the brightness of dromedary milk powders significantly
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47 84 decreased. They also showed that particle morphology was affected by the nature and
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49 85 composition of the feed, degree of heat treatment, and spray-drying parameters (inlet drying air
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51 86 temperature and milk flow-rate).^[22]
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3 87 Spray-drying operating conditions play a key role in the functional properties of cow's
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5 88 milk powder. The properties of cow's milk powder vary considerably depending on the type
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8 89 and composition of the powder, as well as the process conditions of concentration and drying
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10 90 processes.^[23] The reconstitution properties of cow's milk powder such as solubility, wettability,
11
12 91 and dispersibility are mainly affected by the inlet drying air temperature and the dry extract of
13
14 92 the feed concentrate.^[23]

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17 93 In the present study, two sets of spray-drying process conditions were applied on skim
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19 94 dromedary and cow's milks to evaluate the impact of process conditions and milk type on
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21 95 physicochemical properties (proximate composition, water activity, particle size distribution,
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23 96 and color) and rehydration ability of spray-dried powders.

24 25 26 97 **MATERIAL AND METHODS**

27 28 98 *Dromedary and cow's milks*

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30 99 Dromedary (*Camelus dromedarius*) milk was obtained from a local breeding located in
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32
33 100 the south of Tunisia (Gabès governorate, Tunisia). Dromedary milk constituted of pooled milk
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35 101 samples assembled from twenty different healthy dromedaries, whose lactation time ranged
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37 102 between 2 and 8 months. As for the cow's milk, which was provided by a farm located in the
38
39 103 north-east of France (experimental domain of La Bouzule, ENSAIA, Laneuvelotte, France), it
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41 104 was collected from healthy Holstein cows. Both milks were collected in sterile milking cans
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43 105 and 0.02 % (w/w) sodium azide was added to ensure their microbiological stability. Both milks
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45 106 were skimmed at $3\,000 \times g$ during 20 min at 4 °C (Gyrozen 1580MGR, Multi-purpose
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47 107 Centrifuge, Daejeon, Korea). Then, both skim milks were stored at -20 °C until use for spray-
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49 108 drying.

50 51 52 53 54 55 56 110 *Spray-drying of skim dromedary and cow's milks*

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3 111 Skim dromedary and cow's milks were sieved at 50 μm mesh size (stainless steel, 200
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5 112 mm diameter, 50 mm height, Retsch GmbH, Germany) in order to remove the potential
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7 113 remaining coalesced fat globules. The spray-drying of skim milks was performed in a
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9 114 MicraSpray MS 150 simple effect pilot plant spray-dryer (Anhydro, Soeborg, Denmark)
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11 115 equipped with a bi-fluid nozzle (Fluid Cap 60 100 + Air Cap 120, Spraying System, Wheaton,
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13 116 Illinois, USA). Aspiration rate was set at 70 % for all performed assays, corresponding to 155
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15 117 $\text{kg}\cdot\text{h}^{-1}$ drying air flow rate. The spray-dryer was fed at 27 °C with a FAST Load peristaltic pump
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17 118 (VWR, Leuven, Belgium, 48 mm internal pipe diameter). The drying air cocurrently flowed
18
19 119 with the spray of milk droplets in the drying chamber (Figure 1). Two assays differing in spray-
20
21 120 drying conditions (30 L milk per assay) were carried out with a view to evaluate the influence
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23 121 of air outlet temperature (Table 1). The spray-drying conditions were selected based on
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25 122 literature [11] and after preliminary experimentations in order to obtain skim milk powders
26
27 123 suitable for storage (i.e. having a moisture content not exceeding 5 % (w/w) and water activity
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29 124 values ranging between 0.2 and 0.4).[11]

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31 125 The powders were then collected, immediately packed in polyethylene terephthalate
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33 126 bags and stored at 10 °C until analysis. All analyses were carried out within a week after powder
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35 127 production. Spray-drying yield was calculated as the ratio between the dry mass of powder and
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37 128 the dry mass of feed skim milk.

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Proximate composition of skim dromedary and cow's milks

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131 Dry matter, protein, and ash contents of skim dromedary and cow's milks were
132 performed according to the AOAC standard methods.[24] Dry matter was determined by drying
133 10 mL milk at 103 °C for 5 h in a capsule containing Fontainebleau sand (1:10 (w/w) milk
134 sample/Fontainebleau sand). Ash content was determined by weight loss after incinerating 10
135 mL milk sample in a furnace at 550 °C during 6 h. The total nitrogen content was determined

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3 136 according to Kjeldhal method (10 mL of milk sample), and protein content was deduced from
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5 137 total nitrogen content by multiplying by a conversion factor of 6.38. Fat content was determined
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7 138 according to the Gerber acid-butyrometric method (11 mL of milk sample). Carbohydrates
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10 139 content was deduced by difference with other components according to equation 1 assuming
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12 140 that vitamins were weakly represented:

$$141 \quad \text{Carbohydrates content (\%)} = 100 - \\ 142 \quad (\text{moisture content} + \text{protein content} + \text{ash content} + \text{fat content}) \quad (\text{Equation 1})$$

143

144 *Dynamic viscosity of skim dromedary and cow's milks*

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

148

149 *Proximate composition of skim dromedary and cow's milk powders*

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

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

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

161 *Water activity*

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3 162 Water activity of spray-dried powders (10 g) was measured using a water activity meter
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5 163 (HygroPalm23-AW, Rotronic, France) in quick mode at 25 °C.
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10 165 ***Particle size distribution***
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12 166 Particle size distributions of skim dromedary and cow's milk powders were determined
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14 167 with a laser granulometer (Mastersizer 3000 Malvern Instruments, UK), equipped with He-Ne
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16 168 laser light (632.8 nm wavelength), using dry dispersion with the Aero S module. Dispersion
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18 169 conditions were as follows: 2 bar, 100 % air pressure, 100 % feed rate, and 3 mm hopper length.
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20 170 The median diameter in volume was chosen as particle size estimator. Classical granulometric
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22 171 parameters D_{10} , D_{50} , and D_{90} were recorded (D_X corresponds to the size for which X % of the
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24 172 particle population has smaller size). Span was calculated to evaluate the width of the particle
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26 173 size distribution (equation 2):
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$$Span = (D_{90} - D_{10})/D_{50} \text{ (Equation 2)}$$

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33 175 ***Colorimetric analysis***
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35 176 The color of skim dromedary and cow's milk powders was measured using a colorimeter
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37 177 (Konica Minolta, Inc, Japan) in the CIEL*a*b* system. The colorimetric parameters L^*
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39 178 (lightness), a^* (redness/greenness), and b^* (yellowness/blueness) were determined. L^* , varying
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41 179 from 0 to 100, describes sample lightness (low values for darkness, high values for lightness).
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43 180 a^* varies from -100 to 100 and represents the green-magenta color scale, with negative values
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45 181 for greenness and positive values for redness. b^* ranges from -100 to 100 and corresponds to
46
47 182 the blue-yellow color scale, with negative values for blueness and positive values for
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49 183 yellowness. The chroma (C^*) and hue angle (H°), representing the saturation level and shade
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51 184 of the color, respectively, were calculated as follows (equations 3 and 4).^[26]
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$$C^* = \sqrt{a^{*2} + b^{*2}} \text{ (Equation 3)}$$

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3 187 $H^\circ = \arctan (b^*/a^*)$ (Equation 4)
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8 189 ***Scanning electron microscopy***

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10 190 The morphological properties of skim dromedary and cow's milk powders were
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12 191 determined using scanning electron microscopy (Hitachi S-4800, Japan) operated at 1 kV.
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14 192 Powders were stuck onto the adhesive carbon tabs (JEE-420, Japan). The milk powder samples
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16 193 were then coated with carbon. Topographic images were taken for each milk powder at different
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18 194 magnifications (200 ×, 600 ×, 2 000 ×, 10 000 ×, and 45 000 ×).
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24 196 ***Rehydration properties***

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26 197 ***Solubility index***

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28 198 Solubility represents the mass percentage of soluble matter in powders, it was
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30 199 determined according to ISO 8156:2005 standard method.^[27] First, 2.5 g skim milk powder was
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32 200 vigorously mixed with 17.5 mL distilled water at 22 °C in a Falcon tube during 30 s. The
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34 201 suspension was then centrifuged at 1 800 × g (Heraeus Megafuge 8R Centrifuge, Germany) at
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36 202 room temperature (22 °C) and the supernatant was collected. The supernatant dry matter was
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38 203 determined by drying at 103 °C in an air oven for 15 h. The solubility index SI was determined
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40 204 using the following equation 6:
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44
45 205 $SI (\%) = 100 - (M * 100/2.5)$ (Equation 6)
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47 206 Where M designates the sediment mass (g).
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49 207 ***Wetting time***

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51 208 The wetting time is defined as the time expressed in seconds required for a powder to
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53 209 become completely wet. ^[28] It was determined by gently pouring 26 g powder at the surface of
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55 210 250 g distilled water at 20 °C in a 250-mL beaker.
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58 211 ***Dispersibility index***
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3 212 The dispersibility index (DI) is the amount of dry matter that can be dispersed in water,
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5 213 expressed as a mass percentage.^[28] To evaluate the dispersibility index, 26 g powder was added
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7 214 to 250 g distilled water at 20 °C and the mixture was stirred with a spatula for 20 s. A filtration
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9 215 of the mixture was carried out using a metallic sieve. The dispersibility index DI was
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11 216 determined using the following equation 7:

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

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18 218 With T: dry matter content of the resulting liquid (% (w/w));

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20 219 W: moisture content of the powder sample (% (w/w)).
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25 221 ***Statistical analysis***

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27 222 All analyses of this study were carried out in triplicate and reported values were
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29 223 means \pm standard deviations. Statistical analysis was performed using the DSAASTAT add-on
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31 224 for Excel 2010 (Microsoft, Redmond, USA). The presence of significant differences between
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33 225 sample results was investigated by one-way ANOVA and the means were separated by Tukey's
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35 226 HSD test at $p \leq 0.05$.
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41 228 **RESULTS AND DISCUSSION**

42 43 229 ***Proximate composition of skim dromedary and cow's milks***

44
45 230 The proximate composition of skim dromedary and cow's milks is summarized in Table
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48 231 2. The proximate composition was significantly different between milk samples. Total solids
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50 232 content was significantly lower for skim dromedary's milk (9.52 % (w/w)) than for skim cow's
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52 233 milk (12.05 % (w/w)). Protein and ash contents were significantly higher for skim dromedary's
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54 234 milk. Carbohydrates content was significantly lower in the case of skim dromedary's milk.
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56 235 These differences could be attributed to the milk type, animal feed, geographic location, and
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58 236 veterinary practices.^[1] Similar results were obtained by Al Haj and Al Kanhal^[1] who reported
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3 237 that ash content of dromedary milk ranged between 0.60 and 0.90 % (w/w) on dry basis. Zouari
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5 238 et al.^[21] obtained similar results for proteins and ash but lower carbohydrates (lactose) content
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7 239 for skim dromedary and cow's milks. The proximate composition of skim cow's milk obtained
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9 240 in the current study was in agreement with the ranges of proximate composition of skim cow's
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11 241 milk reported by other researchers.^[16] Although both milks were skimmed in the current study,
12
13 242 the fat content of both samples was still higher than that usually observed for skim dromedary
14
15 243 and cow's milks. These results could be justified by the fact that the conditions used for milk
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17 244 skimming by centrifugation in this study were soft compared to what is commonly realized in
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19 245 the literature. Therefore, both milks were considered to be partially skim milks.
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26 247 *Proximate composition of skim dromedary and cow's milk powders*

28 248 Table 3 displays proximate composition, water activity, and spray-drying yield for skim
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30 249 dromedary and cow's milk powders. Total solids content, ranging from 92.96 to 97.01 % (w/w),
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32 250 significantly differed between all spray-dried skim milk powders. Both skim dromedary and
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34 251 cow's milk powders resulting from the second spray-drying assay led to the highest proportions
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36 252 of total solids (97.01 and 96.63 % (w/w), respectively). This was consistent with the fact that a
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38 253 higher air outlet temperature generally induces the formation of powder with a higher total
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40 254 solids content.^[11] According to Chever et al.^[29], the total solids content of milk powder is
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42 255 affected by milk proximate composition, the air outlet temperature during spray-drying, and the
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44 256 residence time in the spray-dryer. It has also been reported that a small increase in the air outlet
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46 257 temperature during spray-drying can have a substantial effect on powder moisture content. In
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48 258 fact, a temperature increase of 1 °C is reported to cause a decrease in powder moisture content
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50 259 of 0.2 % (w/w) on wet basis.^[11,30] Similar results have been reported by Habtegebriel et al.^[16]
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52 260 for skim dromedary milk powder, Langrish et al.^[31] for skim cow's milk powder, and de
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54 261 Oliveira et al.^[32] for whole goat milk powder. Spray-drying conditions did not have a significant
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3 262 impact on the proximal composition of studied milk powders. As it can be seen from Tables 2
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5 263 and 3, the proximate compositions of skim milk powders are comparable to those of their
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7 264 corresponding milks. Besides, protein contents of skim milk powders were neither significantly
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9 265 affected by the milk type nor by spray-drying conditions. The protein contents reported for skim
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11 266 dromedary milk powders spray-dried at 75 and 85 °C were equal to 22 and 23 % (w/w),
12
13 267 respectively. The lower protein contents obtained for skim dromedary milk powders could be
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15 268 attributed to the lower protein content of dromedary milk used to feed the spray-dryer.
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17 269 Habtegebriel et al.^[16] showed that spray-dried skim dromedary milk powders contained 44 - 49
18
19 270 % (w/w) proteins. The higher total lipids content of produced powders might explain the lower
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21 271 content in proteins found in the present study. Although no significant difference was observed
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23 272 in ash content between skim dromedary and cow's milks (Table 2), spray-drying process
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25 273 conditions had a significant impact on ash content (Table 3). The ash contents of skim
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27 274 dromedary milk powders of the current study were similar to the 10 % (w/w) ash content
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29 275 reported by Habtegebriel et al.^[16] for skim dromedary milk powder. For skim cow's milk
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31 276 powders, the obtained ash contents, ranging from 6.41 to 6.63 % (w/w), were a little lower than
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33 277 those reported by Deeth and Hartanto^[33], ranging from 7.5 to 8.0 % (w/w).

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35 278 The water activity of spray-dried powders was mainly affected by spray-drying
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37 279 conditions. In fact, it was close to 0.4 at 75 °C air outlet temperature, whereas it ranged between
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39 280 0.2 and 0.3 at 85 °C air outlet temperature. This was consistent with the fact that powder water
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41 281 activity is negatively correlated with total solids content,^[11] which was also observed in this
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43 282 study. Skim dromedary and cow's milk powders had close water activity after spray-drying at
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45 283 75 °C air outlet temperature, but skim dromedary milk powder had a lower water activity than
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47 284 skim cow's milk powder after spray-drying at 85 °C air outlet temperature. Water activity is an
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49 285 important parameter for food preservation. At water activities around 0.3, microbiological
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51 286 growth, lipid oxidation, and Maillard reaction have very low reaction rates.^[34] It has been shown
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3 287 that a water activity between 0.2 and 0.3 at 25 °C is suitable to achieve optimal stability of milk
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5 288 powders.^[34] Therefore, in our study, it was noticed that the conditions of the second spray-
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7 289 drying assay (85 °C air outlet temperature) were more favorable to the preservation of skim
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10 290 dromedary and cow's milk powders.

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12 291 The spray-drying yield is an important parameter for the cost-effectiveness of food
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14 292 preservation. For all spray-drying conditions, the process yields reported in this study (Table 3)
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16 293 seemed to be low for several reasons. Indeed, the pilot spray-dryer used in this study has a large
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18 294 wall area relative to the drying room volume compared to industrial equipment, which promotes
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20 295 material loss by wall sticking. Besides, the low total solids content of the feeding concentrate
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22 296 (skim milk here) contributes to the formation of small-sized particles.^[35] A non negligible
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24 297 proportion of the powder was therefore not retained by the cyclone and escaped with the outlet
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26 298 air. Finally, the presence of residual fat could also favor the stickiness of produced powders.^[31]
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28 299 Powder stickiness is the primary factor affecting the spray-drying yield. A sticky powder is able
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30 300 to adhere to the walls of the spray-drying chamber, enhancing material losses. Stickiness occurs
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32 301 when using drying temperatures slightly over the glass transition temperature of lactose in
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34 302 milks, i.e. in the temperature range comprised between lactose glass transition temperature
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36 303 (55.6 °C) and about 30 °C over.^[36] Recently, Zouari et al.^[21] reported that using an air outlet
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38 304 temperature of 76.5 °C, the glass transition temperatures were 40 and 37.8 °C for skim
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40 305 dromedary and cow's milk powders and 40 °C, respectively. With the increase in air outlet
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42 306 temperature up to 86.8 °C, the same authors obtained glass transition temperatures of 44 and
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44 307 41.5 °C for skim dromedary and cow's milk powders, respectively. Based on these results, it
45
46 308 can be concluded that the two air outlet temperatures used in our study were over the sticky
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48 309 points of skim dromedary and cow's milk powders, thus leading to a great proportion of powder
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50 310 loss by sticking to the spray-dryer walls. The residual fat and the fineness of produced powders
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52 311 could probably explain the low spray-drying yields. If the spray-drying operation lasted longer,
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3 312 the processing yields would have been improved because the spray-dryer walls would have
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5 313 been covered with powder after a moment, which could thereafter limit the deposition of new
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8 314 powder particles.

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10 315 In the present study, spray-drying yields were greater at the higher air outlet temperature
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12 316 (85 °C), especially for skim dromedary milk powders (51.26 % at 85 °C outlet air temperature
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14 317 vs 19.81 % at 75 °C outlet air temperature). Spray-drying yields were significantly negatively
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16 318 correlated to water activity (Pearson's correlation coefficient r of 0.94). Therefore, it was noted
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18 319 that spray-drying conditions had a greater effect on dromedary milk powders. In accordance
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20 320 with these results, De Oliveira et al.^[32] reported that higher yields are obtained at lower relative
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22 321 humidity of the outlet air, i.e. when the outlet temperature is high and/or the feed flow-rate is
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24 322 low. Habtegebriel et al.^[16] also reported that the increase in the air outlet temperature is likely
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26 323 to enhance cyclone recovery. Actually, it can be predicted that it increases heat and mass
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28 324 transfer in the drying air, thus improving the drying rate and limiting powder stickiness. Similar
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30 325 results were reported by Gallo et al.^[37] who found that the drying air and feed flow-rates as well
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32 326 as the outlet temperature are determinant for the spray-drying yield.

37 327 ***Particle size distributions of skim dromedary and cow's milk powders***

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39 328 Particle size distribution is a very important physical property of milk powders, known
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41 329 for its significant impact on the reconstitution properties of milk powders. Indeed, large
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43 330 particles within a narrow particle size distribution could enhance the rehydration properties of
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45 331 milk samples.^[38] Particle size distributions and granulometric parameters of spray-dried
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47 332 powders are respectively displayed in [Figure 2](#) and [Table 4](#), respectively.

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49 333 The particle size distributions of spray-dried skim milk powders were monomodal and
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51 334 centered around 14 - 20 μm , consistently with previous results obtained with the same
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53 335 combination of pilot spray-dryer and bi-fluid nozzle.^[39,40] The dispersion of particle sizes
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55 336 around the median value was relatively low, as indicated by the moderate values of span ranging
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3 337 from 1.75 to 1.93. Although the spray-drying conditions seemed not to influence the particle
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5 338 size distribution, it was noted that the particles of skim dromedary milk powder were smaller
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8 339 than those of skim cow's milk powders. Furthermore, the higher total solids content of feed
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10 340 skim cow's milk may justify this result. Indeed, its viscosity was higher (3.89 ± 0.12 mPa.s)
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12 341 than that of feed skim dromedary milk (2.96 ± 0.13 mPa.s) (Table 2), leading to larger sprayed
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14 342 droplets,^[35] resulting in larger spray-dried particles. Another cause may be attributed to the
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16 343 higher fat content of skim cow's milk powder, which makes it stickier. In fact, fat, composed
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18 344 of sticky components (with a fusion temperature inferior to 80 °C), is known to concentrate at
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20 345 particle surface during spray-drying due to buoyancy in sprayed droplets,^[41-44] making them
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22 346 more prone to agglomeration, thus leading to particle size increase. According to Fournaise et
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24 347 al.^[45], D_{50} of whole cow's milk powder produced in similar spray-drying conditions was 27.7
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26 348 μm with a span of 3.0, which is consistent with the present study. At last, the higher total solids
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28 349 of feed cow's milk may have limited particle shrinkage during drying owing to the faster
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30 350 solidification of surface-active molecules located at the droplet/particle surface (caused by the
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32 351 higher molecular concentration at the droplet/particle surface and the lower mass transfer inside
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34 352 the droplet/particle due to its higher viscosity), thus also acting in favor of higher particle size.
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36 353 Significant differences were obtained for the granulometric parameters of spray-dried powders,
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38 354 both owing to milk type and spray-drying conditions. No significant influence of spray-drying
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40 355 conditions was observed for dromedary skim milk powders. However, when increasing the air
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42 356 outlet temperature, cow's skim milk powders presented slightly higher median particle sizes.
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44 357 The difference was statistically significant, with median particle size of 17.09 μm at 75 °C air
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46 358 outlet temperature and 19.19 μm at 85 °C air outlet temperature for cow's skim milk powders.
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48 359 Ogolla et al.^[22] have reported that an increase in inlet air temperature and a decrease in milk
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50 360 flow rate caused the formation of smaller particles. However, the effect of drying temperature
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52 361 was different in our study. This difference could be attributed to the fact that a higher drying
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3 362 temperature accelerates the drying rate of droplets, promoting the fast formation of a crust at
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5 363 their surface, and therefore limit shrinkage, which leads to larger particles.^[46]
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8 364 The span showed small significant differences between all spray-dried milk powders.
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10 365 However, there is no marked effect of either the milk type or the spray-drying conditions on the
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12 366 span. Indeed, for skim dromedary milk powders, the increase in the air outlet temperature
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14 367 resulted in a slight decrease in the span values from 1.93 to 1.76. For skim cow's milk powders,
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16 368 span values were about 1.75 and 1.81 at 75 and 85 °C air outlet temperature, respectively.
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20 21 370 *Color of skim dromedary and cow's milk powders*

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24 371 Table 4 displays the color parameters of skim dromedary and cow's milk powders.
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26 372 Whatever the spray-drying conditions and the milk type, the produced powders were very bright
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28 373 (L* was elevated), had a low color saturation (C* was very low), and their main color was
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30 374 green-yellow (owing to H° values). Hence, spray-dried powders appeared relatively white, as
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32 375 such a lowly-saturated color cannot be detected by the human eye at this high level of
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34 376 brightness. Skim cow's milk powders were significantly yellower than skim dromedary milk
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36 377 powders whatever the spray-drying conditions. ~~This could probably be due to the higher~~
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38 378 ~~residual fat content in skim cow's milk powders.~~ This could probably be attributed to the lower
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40 379 content in β -carotene of skim dromedary milk powders compared to skim cow's milk powders.
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44 380 [47,48]

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47 381 Although spray-drying at higher air temperature seemed not to affect brightness and
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49 382 main color, it slightly increased color saturation, which could contribute to the promotion of
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51 383 consumer acceptability of these powders. This increase in powder color saturation may be
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53 384 related to the Maillard reaction susceptible to occur between milk proteins and lactose, known
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55 385 to be enhanced at higher temperature.^[34,49,50] These findings could also be attributed to the lower
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57 386 moisture content of powders spray-dried at higher temperatures.^[22] Similar results were
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3 387 previously obtained by Ogolla et al.^[22] and Sulieman et al.^[18] who investigated the effect of the
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5 388 inlet air temperatures on the color of spray-dried dromedary milk powders. These authors
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8 389 reported that higher inlet drying air temperatures resulted in decreased L* and hue angles while
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10 390 increasing the a*, b* and chroma values of spray-dried dromedary milk powders.

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12 392 *Morphology and surface appearance of skim dromedary and cow's milk powders*

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15 393 The scanning electron micrographs of skim dromedary and cow's milk powders are
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17 394 presented in Figure 3. Whatever the spray-drying conditions and the milk type, spray-dried
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19 395 powders appeared as agglomerates of small particles rather than single particles. Small
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21 396 agglomerates with angular and homogeneous shape are visible in Figure 3. Furthermore, the
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23 397 particles had a shriveled appearance as well as an irregular and rough surface, which is the
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25 398 classical shape of skim milk powders. Few pores could be detected at their surface, as pointed
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27 399 out by arrows in Figure 3 D2 f and C2 f. Habtegebriel et al.^[16] reported that, independently of
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29 400 spray-drying conditions, whole dromedary milk powders had a smooth surface, covered by a
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31 401 fat layer, whereas skim dromedary milk powders presented a rougher surface. Similar results
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33 402 were reported by other researchers^[23,31] which showed that skim cow's milk powders are
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35 403 composed of flat, wrinkled, and collapsed particles. Furthermore, it has been shown that the
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37 404 presence of surface fat makes particles sticky, enhancing their tendency to form
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39 405 agglomerates.^[31] This may be the case in our study given the significant fat content of skim
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41 406 dromedary and cow's milk powders probably leading to a high proportion of surface covered
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43 407 by fat^[38] and the presence of numerous agglomerates evidenced by SEM images. Habtegebriel
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45 408 et al.^[16] added that the presence of pores at the particle surface might facilitate water diffusion
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47 409 into the powder, thus enhancing its rehydration ability. Few pores were observable at the surface
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49 410 of particles spray-dried in our study, probably due to the presence of fat, which may be related
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51 411 to the hypothesized stickiness of particles. **Furthermore, at higher air outlet temperature, particle**

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3 412 ~~agglomerates seemed to be denser and the particles appeared more tightly bound (Figure 3: D2e~~
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5 413 ~~and C2e).~~
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10 415 ***Rehydration ability of skim dromedary and cow's milk powders***
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12 416 The reconstitution properties of skim dromedary and cow's milk powders are presented
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14 417 in Table 4. All spray-dried powders could be considered as non-wettable, as their wettability
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16 418 time was higher than 120 s.^[51] This poor wettability can mainly be attributed to the fineness of
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18 419 powders produced with the combination of pilot spray-dryer and bi-fluid nozzle employed in
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20 420 this study.^[39] In fact, the larger the particle, the higher its weight, and thus the more easily the
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22 421 particle can overcome water surface tension and immerse in water. It has been reported in the
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24 422 literature that a median particle size over 200 μm promotes powder wetting.^[52] Moreover, it has
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26 423 previously been reported that large particles are more prone to have large surface pores, which
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28 424 results in fast wetting.^[38] According to Gaiani et al.^[41], the wetting step mainly depends on
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30 425 particle surface charge, surface activity, size, porosity, surface composition (especially,
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32 426 proportion of hydrophilic compounds), contact angle between the powder bed and water, and
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34 427 powder density. Besides, the poor wettability of dairy powders has also often been attributed to
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36 428 the presence of various hydrophobic compounds (lipids, caseins, etc.) at the particle surface.^[38]
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38 429 Kim et al.^[38] reported a wetting time over 15 min for whole milk powder. Spray-dried powders
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40 430 produced in the current study had a non-negligible fat content, which can lead to a large fraction
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42 431 of the surface covered by lipids and explain their poor wettability.
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49 432 Moreover, all investigated spray-dried powders could be considered as hardly
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51 433 dispersible. Indeed, their dispersibility indices were well lower than 95 %.^[51] Spray-drying
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53 434 conditions had an opposite effect on the rehydration behavior of the two types of milk powders.
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55 435 It is evident from Table 4 that dispersibility was positively correlated with the air outlet
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57 436 temperature for skim dromedary milk powder. Actually, the dispersibility index increased from
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3 437 34.84 % at 75 °C air outlet temperature to 41.82 % at 85 °C air outlet temperature. Concerning
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5 438 the air outlet temperature, it had no significant difference on dispersibility indices of skim cow's
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7 439 milk powders. These results could also be attributed to granulometric characteristics of skim
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9 440 dromedary and cow's milk powders. In fact, and generally, the larger the mean particle size, the
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11 441 higher the dispersibility index.^[53] According to Chever et al.^[29], a rapid dispersion requires
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13 442 particle sizes in the range from 150 to 200 µm, which is not the case in our study. However, for
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15 443 powders produced in the present study, dispersibility and median particle size were highly
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17 444 positively correlated (Pearson's correlation coefficient of 0.89), in agreement with the literature
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19 445 ^[53]. The higher fat content of cow's milk probably led to the formation of stickier particles, thus
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21 446 more difficult to disperse due to the presence of more interparticular interactions.
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26 447 In general, milk powders are considered to be soluble if their solubility index is higher
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28 448 than 99 %.^[51] Solubility is known to be mainly affected by powder composition, especially by
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30 449 the nature and structure of proteins.^[54] Skim dromedary and cow's milk powders produced in
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32 450 our study could be considered as fairly soluble, as their solubility indices ranged between 78.31
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34 451 and 95.26 %. Besides, the spray-drying conditions did not have the same effect on the
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36 452 rehydration properties depending on the milk type. On one hand, skim dromedary milk powder
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38 453 produced at 85 °C air outlet temperature showed a significantly higher solubility index (95.26
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40 454 %) than the same powder spray-dried at 85 °C outlet air temperature (91.95 %). On the other
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42 455 hand, skim cow's milk powder revealed significantly higher solubility when spray-dried at 75
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44 456 °C outlet air temperature. These results could be related to the significant lower fat content of
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46 457 skim dromedary milk powders and the difference in particle size distributions of studied
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48 458 powders. Indeed, Pearson's correlation coefficient between solubility and median particle size
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50 459 was 0.66, indicating a medium positive correlation. Besides, whatever the spray-drying
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52 460 conditions, dromedary skim milk powders had slightly better rehydration properties, which
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54 461 could also be related to the sensitivity of cow's proteins to thermal denaturation. In fact, it has
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3 462 been reported that spray-drying of whole dromedary milk did not cause any noticeable damage
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5 463 to its protein fraction, resulting in a higher solubility of dromedary milk powder than cow's
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7 464 milk powder.^[55] Additionally, Anandharamakrishnan et al.^[56] reported that increasing the outlet
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9 465 air temperatures causes partial protein denaturation and subsequent protein aggregation,
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11 466 inducing solubility loss, as observed for cow's milk powders produced in the present work.
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13 467 From these results, it can be concluded that increasing air outlet temperature did not improve
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15 468 the rehydration characteristics of dromedary and cow's skim milk powders, as rehydration
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17 469 mainly depends on particle size, which was very little affected when changing the outlet air
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19 470 temperature.

23 471 **CONCLUSION**

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26 472 This study pointed out that spray-drying is a good technique to stabilize dromedary milk
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28 473 and postpone its use. Spray-drying conditions have a noticeable effect on powder
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30 474 physicochemical properties and rehydration ability. In this study, skim dromedary and cow's
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32 475 milks were spray-dried without prior concentration to avoid introducing another source of
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34 476 process variability. The findings indicated that the outlet drying air temperatures significantly
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36 477 influenced the physical and rehydration properties of obtained powders. Overall, applying an
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38 478 air outlet temperature of 85 °C led to better chemical and physical properties for both milk
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40 479 powders. Indeed, a higher air outlet temperature (85 °C) resulted in higher spray-drying yields
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42 480 and skim dromedary and cow's milk powders with higher total solid contents and lower water
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44 481 activity, which is favorable for preservation purposes. When increasing the air outlet
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46 482 temperature, skim dromedary and cow's milk powders presented higher median particle sizes.
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48 483 Spray-drying at 85 °C outlet temperature seemed not to affect powder brightness and main
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50 484 color, but it slightly increased color saturation. The results of the present study revealed that
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52 485 regardless of process conditions and milk type, skim milk powders spray-dried at pilot scale
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54 486 could be considered as non-wettable, hardly dispersible, and fairly soluble. However, slightly
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3 487 better rehydration properties were obtained for dromedary skim milk powders spray-dried at 85
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5 488 °C outlet air temperature. The SEM analysis showed that spray-dried skim milk powders were
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8 489 composed of agglomerates of small particles with angular and homogeneous shapes. This could
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10 490 be detrimental to their flow properties and may result in handling issues when conveying or
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12 491 storing these powders. Therefore, it will be interesting in further research works to investigate
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14 492 the flow properties of skim dromedary and cow's milk powders spray-dried at pilot scale.
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18 19 494 **DISCLOSURE STATEMENT**

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22
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27
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3 685 **Figure captions**
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6 686 **Figure 1.** Schema (A) and dimensions (B) of the Micra Spray MS 150 single-effect spray tower.
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9 687 **Figure 2.** Particle size distributions of skim dromedary and cow's milk powders.
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12 688 **Figure 3.** Scanning electron micrographs of skim dromedary and cow's milk powders. D1:
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14 689 Dromedary_C1; D2: Dromedary_C2; C1: Cow_C1; C2: Cow_C2. Magnifications: 200 × (a),
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16 690 600 × (b), 2 000 × (c), 4 000 × (d), 10 000 × (e), and 45 000 × (f).
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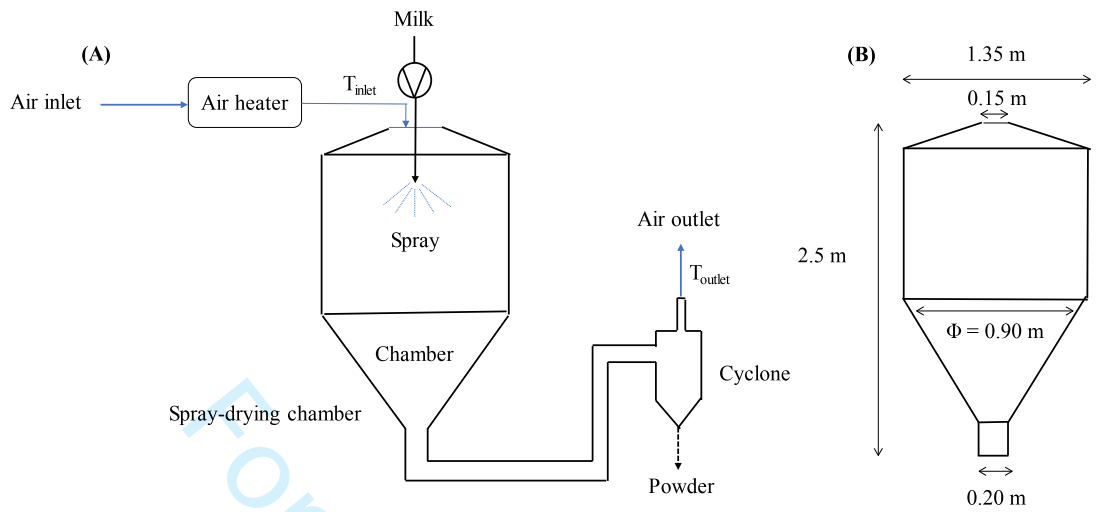


Figure 1

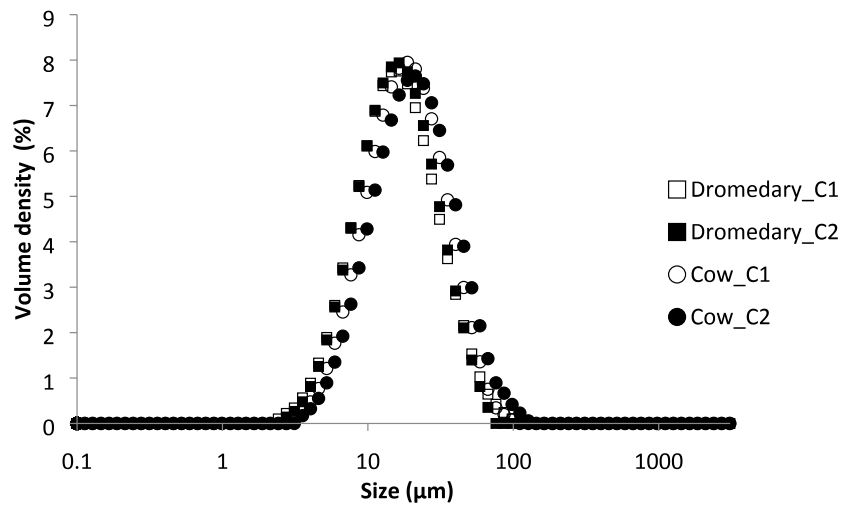


Figure 2

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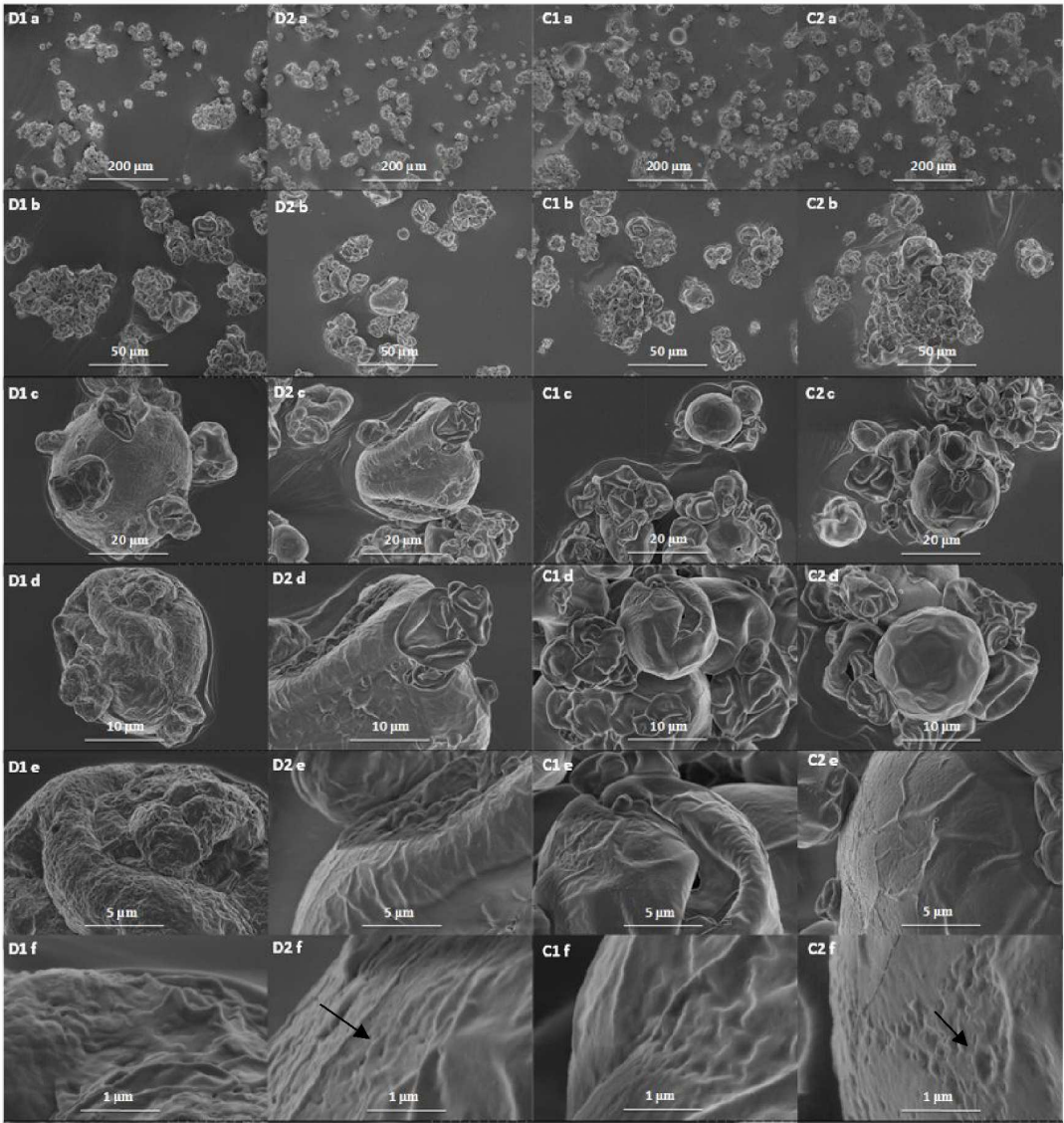


Figure 3

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

Powder acronym	sample	Air inlet temperature (°C)	Air outlet temperature (°C)	Feed flow rate (mL.min ⁻¹)
	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 ($p < 0.05$).