Effects of milk somatic cell counts on some physicochemical and functional characteristics of skim and whole milk powders

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ABSTRACT

The aim of this work was to study the influence of milk somatic cell count (SCC) levels on spray-dried milk powders. For this reason, 3 cow milks with different SCC (<300,000, 300,000–700,000, >700,000 SCC/mL) were processed into skim (SMP) and whole milk powder (WMP). The effect of SCC on the physicochemical and functional characteristics of the milk powders and textural properties of set-type yogurts produced from reconstituted milk powders with different SCC was evaluated. A crucial difference was noted between milk powders depending on different SCC. Protein values and ash content of powder samples decreased correlatively with increasing SCC. The hydroxymethylfurfural content of SMP was higher than WMP. We noted an increase in hydroxymethylfurfural content of both SMP and WMP depending on elevated SCC. Solubility index of SMP and WMP was 1.280 to 1.632 and 0.940 to 1.208 mL, respectively; with increasing SCC, solubility index was affected adversely. The highest foam stability was determined in SMP containing >700,000 SCC. Bulk density of SMP and WMP was between 0.682 and 0.708 and 0.660 to 0.685 g/cm³, respectively. An increase was observed in scorched particle of both SMP and WMP depending on increasing SCC. We found significant differences in particle size distribution of milk powders produced from milk with SCC at different levels. Although WMP had more uniform and big particle structure, SMP had more specific area. A negative correlation was noted between yogurt texture and SCC. Results indicate that milk SCC has negative influences on milk powder quality.

Key words: somatic cell count, milk powder quality, particle size

INTRODUCTION

Mastitis, an inflammation of the mammary gland, is the most prevalent infectious disease of adult dairy cattle (Andrews et al., 2004). Somatic cell count in milk is generally used as an important indicator of mastitis. In the dairy industries of many countries, SCC is widely used for monitoring hygienic milk quality and pricing of raw milk (Suriyasathaporn et al., 2006). The dairy industry has provided a bonus payment program to promote reduced raw milk SCC (Ma et al., 2000).

High SCC causes economic losses in dairy industry. The main reason for economic losses related to elevated SCC is decreased milk yield in cows (Munro et al., 1984; Huijps et al., 2008; Hagnestam-Nielsen et al., 2009). Besides decreasing milk yield, increased SCC in milk adversely affects quality of raw milk and dairy products.

Some studies have shown that an increase in SCC leads to a modification in milk composition. It was reported that elevated SCC results in both decreased protein concentration and casein content (Munro et al., 1984; Lee et al., 1991; Wickström et al., 2009), whereas noncasein nitrogen and whey protein increased (Rogers et al., 1989a; Auldist and Hubble, 1998). Previous studies reported that elevated SCC causes a decrease in the concentration of milk lactose (Miller et al., 1983; Rogers et al., 1989b; Shuster et al., 1991; Auldist et al., 1995) and milk fat (El Deeb and Hassan, 1987; Auldist et al., 1995). Also, SCC changes the mineral balance of milk, and these changes can play significant roles in determining the manufacturing quality of the milk (Auldist and Hubble, 1998). Although high SCC decreases potassium, it increases sodium (Rogers et al., 1989b; Auldist et al., 1995; Chaudhury et al., 1995), and El-Deeb and Hassan (1987) and Lee et al. (1991) showed a decrease in total calcium as SCC increases.

Using high-SCC milk for cheesemaking is associated with decreased curd firmness (Politis and Ng-Kwai-Hang, 1988b) and cheese yield (Politis and Ng-Kwai-Hang, 1988a; Barbano et al., 1991; Auldist et al., 1996b; Klei et al., 1998), increased fat and casein loss

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in whey (Politis and Ng-Kwai-Hang, 1988a) and clotting times (Lee et al., 1991; Mijacevic et al., 1993), and compromised sensory quality (Munro et al., 1984). Increased SCC in milk caused an increment in fatty acids in the resulting yogurt during storage that may result in a decrease in the shelf life of the product (Fernandes et al., 2007). Oliveira et al. (2002) studied the composition and sensory attributes of yogurt produced with different SCC and reported that sensory quality of yogurt produced from milk with high SCC decreased.

It has been shown that elevated SCC reduced the shelf life and sensory quality of pasteurized milk, mostly by a higher fatty acid rate during storage (Janzen, 1972; Rogers et al., 1989b; Ma et al., 2000). It was also reported that high SCC could lead to poor heat stability of full-cream milk powder and that the sensory properties of such milk powders deteriorated more quickly than those of powder produced from milk with low SCC (Auldist et al., 1996a).

Previous studies have focused on raw milk and other dairy products; very little information exists on the influence of SCC on the quality of milk powders. To the best of our knowledge, no data is available on the possible effects of SCC on particle size distribution in spray-dried skim and whole milk powders. The aim of our study was to investigate the effects of different SCC levels in raw milk on physicochemical and functional properties of skim (SMP) and whole milk powder (WMP). Moreover, textural properties of yogurts produced from reconstituted SMP and WMP with SCC at different levels was determined.

MATERIALS AND METHODS

Milk Collection

Raw cow milk was supplied from Enka Dairy and Food Products Industry and Commerce Ltd., Konya, Turkey. The Enka Dairy plant is a large-scale company with 5,000 milk producers. Once milk from 50 dairy farms (50–500 cows per farm) is collected in 15 milk collection centers, the milk is cooled to 4°C and transported to processing center with 10-t stainless steel tanks. Each tank contains milk from 150 milk producers (5–20 cows per milk producer). For determination of SCC in milk, 3 samples were taken from each bulk milk tank and analyzed in triplicate for each group. After raw milk analysis, the bulk milk with desired SCC was taken for processing to milk powder. The vast majority of milk was from cross-bred Holstein-Friesian cows. In all farms, milking performed by automatic milking machines in the morning.

Raw Milk Analysis

The physicochemical properties of raw milk (total DM, specific gravity, titratable acidity, fat, ash) were determined according to AOAC method (AOAC International, 2005). The pH was determined by using a 315i/SET pH-meter with a sentix 42 electrode (WTW, Weilheim, Germany). The protein content of milk sample was estimated using a Kjeltex instrument (Kjeltec-8200, Foss Electric, Hillerød, Denmark) by Kjeldahl method (AOAC International, 2005; method 991.20). Fifteen grams of K_2SO_4 , 1 g of $CuSO_4 \cdot 5H_2O$, and 5 g of warm milk ($38 \pm 1^\circ C$) were added to digestion tubes and then 25 mL of H_2SO_4 was added slowly. The digestion tubes were placed on the fume ejection system until digest cleared in flask at a temperature of $410^\circ C$; it was then cooled to room temperature. Digested samples were distilled with 50% NaOH using Kjeldahl distillation unit where steam was distilled over 4% boric acid (50 mL) containing an indicator for 5 min. The ammonia trapped in boric acid was determined by titrating with 0.1 N HCl.

Somatic cell count analyses were carried out with a Fossomatic 90 (Foss Electric) using a previously described method (Gonzalo et al., 1993; IDF, 1995). For the determination of SCC, the milk samples were heated to $40^\circ C$ in a water bath and held at this temperature for 15 min. Then the samples were processed in the Fossomatic 90. All analyses were carried out in triplicate. Before the experiment the instrument was calibrated by using bovine milk standards of known SCC (between 0 and $2,000 \times 10^3$ cells/mL) provided by Cecalait (Poligny, France).

Manufacture of Milk Powders

After raw milk analysis, milk was divided into 3 groups based upon SCC status: low ($<300,000$ SCC/mL), intermediate ($300,000$ – $700,000$ SCC/mL), and high ($>700,000$ SCC/mL). First, raw milk groups were preheated ($63^\circ C$) and standardized (milk fat content: 0.15% for SMP and 3.1% for WMP). Then milk was pasteurized ($85^\circ C$ for 1 min) and concentrated in a falling film evaporator until a concentration of 45% TS was reached. Subsequently, the spray-drying process was conducted in a Spray-Dryer (GEA Niro Atomizer, GEA Process Engineering A/S, Soeborg, Denmark). The inlet and outlet temperatures of the drying air stream were 180 and $70^\circ C$, respectively. The drying process, in each condition, was conducted in duplicate. Milk powder analysis were repeated 3 times for each group.

Manufacture of Yogurts

For set-type nonfat (NFY) and full-fat yogurt (FFY) production, SMP and WMP with 3 different SCC were used. First, SMP and WMP were reconstituted to 12% SNF in all SCC categories. The reconstituted milk was heat-treated at 85°C for 15 min and then cooled to 45°C. Milk groups were inoculated (2% inoculum) with yogurt starter culture (*Streptococcus thermophilus* and *Lactobacillus delbrueckii* ssp. *bulgaricus*, Yogurt 709, Chr. Hansen, Hørsholm, Denmark) and incubated at 45°C, for approximately 3 h until a pH of 4.60 to 4.70 was reached. After incubation, yogurt samples were cooled rapidly to room temperature. Yogurt manufacturing was carried out in duplicate for each group. Texture analysis was carried out 24 h after production of yogurt samples.

Analysis of Milk Powder

Moisture Content. Moisture content of milk powder samples was measured by oven drying at 102°C until constant weight was reached (AOAC International, 2005).

Fat. Fat analyses were carried out using the previously described method (Reddy et al., 2014).

Titrateable Acidity. Titrateable acidity (TA) was determined by titrating the reconstituted milk powder with sodium hydroxide to determine the amount of lactic acid present (ADPI, 2002).

pH. pH was measured using a 315i/SET pH-meter with a Sentix 42 electrode (WTW) after a 10-g sample was dissolved in 100 mL of distilled water. Standard buffer solutions (pH 4.01 and 7.01; WTW) were used for calibration.

Protein. The protein content of milk powder samples was estimated by using Kjeltex instrument (Kjeltex-8200, Foss Electric) by Kjeldahl method (AOAC International, 2005; method No. 930.29). For determination of protein in milk powder samples, precisely 1 g of milk powder sample was weighed and the analysis was repeated as described in raw milk analysis. The percent protein was calculated on total nitrogen basis using the following equation:

$$\text{Nitrogen (\%)} = \frac{(v_{\text{sample}} - v_{\text{blank}}) \times 0.1 \times 14.007}{w_{\text{sample}} \times 1000} \times 100,$$

where v_{sample} and v_{blank} indicate HCl (mL) for sample and blank, respectively. Thus, percent protein was

$$\text{Protein (\%)} = \text{N (\%)} \times 6.38.$$

Ash. For determination of ash content in milk powders, precisely 1 g of milk powder sample was weighed into a crucible and heated in muffle furnace at a temperature of 550°C until carbon-free ash was obtained (AOAC International, 2005).

Water Activity. Water activity (a_w) of milk powders was determined by Novasina LabTouch- a_w instrument (Novasina AG, Lachen, Switzerland). Salt-T relative humidity standards (Novasina AG, Lachen, Switzerland) were used for calibration.

Hydroxymethylfurfural Content. Hydroxymethylfurfural (HMF) content was measured using the previously described method (Keeney and Bassette, 1959).

Solubility Index. The solubility index was determined according to the American Dairy Products Institute (ADPI, 2002). Milk powders were reconstituted to 10% SNF. The solubility index was reported as milliliters of sediment in conical centrifuge tubes (Art. No 3634, Funke Gerber, Berlin, Germany) after centrifugation (1,100 rpm for 10 min at 55°C).

Foam Stability. The foam stability of milk powders was estimated by a previously described method (Yilmaz et al., 2010). It was recorded as the time passed until half of the original foam volume disappeared.

Dispersibility. Ten grams of milk powder was poured into 250 mL of water at 25°C. The time required for all the powder to be wetted without pellet was measured (A/S Niro Atomizer, 1978).

Wettability. The wettability of milk powders was measured previously described method (Fuchs et al., 2006). Wettability was defined as the time necessary for 1 g of powder to disappear from the surface of 100 mL of distilled water at 20°C without agitation.

Bulk Density. The bulk density of milk powders was measured as the ratio of the mass of an untapped powder sample and its volume after tapping it 100 times in a graduated cylinder (100 mL). The bulk density was expressed in grams per cubic centimeter (g/cm^3 ; A/S Niro Atomizer, 1978).

Color. Color was measured using a Minolta Chroma Meter CR-400 (Minolta, Osaka, Japan). Milk powder samples were placed as a uniform 25-mm layer on a 50-mm diameter petri dish and analyzed for color. The L^* (luminosity), a^* (redness), and b^* (yellowness) values were determined according to the CIE Lab color space system, where L^* corresponds to light or dark chromaticity (varying from 0% dark to 100% light), a^* to green or red chromaticity (varying from -60% green to 60% red), and b^* to blue or yellow chromaticity (changing from -60% blue to 60% yellow). Before the measurements, the instrument was calibrated with a reference tile ($L^* = 97.10$, $a^* = -4.88$, $b^* = 7.04$; Francis, 1998).

Particle Size Measurement. The particle size measurement was carried out by the dry method in

Table 1. Mean composition of raw milk used for the manufacture of milk powders

Parameter	SCC (cells/mL)		
	<300,000	300,000–700,000	>700,000
Total DM (%)	12.08 ± 0.02	11.99 ± 0.02	11.90 ± 0.03
Specific gravity (g/cm ³)	1.033 ± 0.002	1.032 ± 0.001	1.032 ± 0.000
Fat (%)	3.50 ± 0.05	3.50 ± 0.04	3.46 ± 0.02
Titrateable acidity (% lactic acid)	0.132 ± 0.003	0.136 ± 0.001	0.145 ± 0.002
pH	6.80 ± 0.02	6.70 ± 0.01	6.68 ± 0.01
Protein (N × 6.38)	2.93 ± 0.04	2.90 ± 0.02	2.89 ± 0.03
Ash (%)	0.72 ± 0.03	0.70 ± 0.02	0.70 ± 0.04

a laser diffraction particle size analyzer (Mastersizer 2000; Malvern Instruments Ltd., Worcestershire, UK) fitted with a Scirocco 2000 dry powder feeder unit. The results are expressed as: D[4.3] = volume mean diameter; D[3.2] = surface area mean diameter; $d(0.1)$ = 10% of the sample is below this diameter; $d(0.5)$ = 50% of the sample is below this diameter; $d(0.9)$ = 90% of the sample is below this diameter; span = normalizes the width of the distribution relative to the median value n ; uniformity = reflects the magnitude of particle size distribution and the gradient of the particle size distribution curve; and specific surface area = defined as the total area of the particles divided by the total weight.

Scorched Particle. Scorched particles were analyzed according to the method outlined by American Dairy Products Institute Bulletin (ADPI, 2002).

Texture Analysis of Yogurts

The texture of yogurts was measured using a Texture Analyzer TA-XT *plus* (Stable Micro Systems Ltd., Surrey, UK), equipped with a 5-kg load cell. The samples were tested in conical polypropylene pots (h = 88 mm; inside top $\varnothing$ = 62 mm; outside base $\varnothing$ = 54 mm) immediately after removal from storage ($\sim 4^{\circ}\text{C}$), using an extrusion disc ($\varnothing$ = 35 mm) operating at a fixed test speed of 1.0 mm/s to a depth of 30 mm. The force-time curves were analyzed using Texture Expert Exceed (Stable Micro Systems Ltd.) and the textural parameters were expressed as firmness, consistency, cohesiveness, and viscosity index. Triplicate measurements were taken on each sample.

Statistical Analysis

We used SPSS software (version 16.0; SPSS Inc., Chicago, IL) for statistical analysis. The results were analyzed statistically using the variance analysis. Statistically differences among the means were determined by using Duncan's multiple comparison tests at $P < 0.01$.

RESULTS AND DISCUSSION

Physicochemical properties of raw milk are given in Table 1. The results showed that total DM, fat, pH, protein, and ash content of raw milk negatively correlated with SCC. Conversely, TA of raw milk increased depending on elevated SCC.

Moisture, fat, TA, pH, protein, and ash content of milk powders are presented in Table 2. The moisture content of milk powder samples changed from 1.50 to 2.13%, which complied with the legal standards (max 5%; Codex Alimentarius, 1999). Somatic cell count was positively correlated with moisture of powder samples. High moisture content of milk powders leads to decreased flowability and nonenzymatic browning, whereas very low moisture content can cause an increased fat oxidation rate (Labuza and Dugan, 1971; van Mil and Jans, 1991; Fitzpatrick et al., 2007).

The fat content of SMP and WMP samples was 0.5 and 26.5 to 27%, respectively. The fat content of the powders did not change, except WMP with high SCC. According to legal standards, the milk fat of SMP and WMP must be between 0 and 1.5 and 26 to 42% (wt/wt), respectively (Codex Alimentarius, 1999). Our results were in agreement with the legal standards.

Titrateable acidity value of milk powders was between 0.115 and 0.120% (% lactic acid). A slight increase in TA of samples was noted with regard to elevated SCC. It is generally recognized that the maximum acidity of milk powder should not exceed 0.15%; otherwise the solubility of powder can be reduced (Caric, 1994). Auld et al. (1996b) reported that TA of full fat milk powders with high SCC ranged from 0.103 to 0.137%.

pH values of samples were 6.69 to 6.77 and we observed no significant difference between pH values of WMP and SMP containing SCC at same level ($P > 0.01$). Depending on increasing SCC, pH decreased slightly in powder samples.

The protein content of SMP and WMP samples ranged from 34.05 to 34.80 and 22.05 to 23.10%, respectively. According to results, the protein content of powder samples decreased with regard to elevated

Table 2. Moisture, fat, titratable acidity, pH, protein, and ash content of milk powders

Sample	Parameter	SCC (cells/mL)		
		<300,000	300,000–700,000	>700,000
Skim milk powder	Moisture (%)	1.70 ± 0.05	2.00 ± 0.02	2.13 ± 0.06
	Fat (%)	0.5 ± 0.1	0.5 ± 0.0	0.5 ± 0.0
	Titratable acidity (% lactic acid)	0.115 ± 0.002	0.117 ± 0.001	0.118 ± 0.001
	pH	6.75 ± 0.02	6.69 ± 0.01	6.69 ± 0.01
	Protein (%)	34.80 ± 0.03	34.20 ± 0.02	34.05 ± 0.02
	Ash (%)	7.82 ± 0.08	7.54 ± 0.02	7.40 ± 0.04
Whole milk powder	Moisture (%)	1.50 ± 0.12	1.93 ± 0.06	2.03 ± 0.05
	Fat (%)	27.0 ± 0.0	27.0 ± 0.2	26.5 ± 0.4
	Titratable acidity (% lactic acid)	0.116 ± 0.001	0.118 ± 0.002	0.120 ± 0.001
	pH	6.77 ± 0.02	6.70 ± 0.02	6.69 ± 0.00
	Protein (%)	23.10 ± 0.04	22.50 ± 0.02	22.05 ± 0.02
	Ash (%)	6.34 ± 0.04	6.20 ± 0.04	6.05 ± 0.02

SCC ($P < 0.01$). As SMP contains higher proportions of protein due to a much lower fat content, SMP had higher protein content compared with WMP. For SMP and WMP, typical protein content varied from 34 to 37 and 24.5 to 27%, respectively (ADPI, 2002).

The ash content of milk powder samples changed from 6.05 to 7.82%. A negative correlation was also noted between SCC and ash content of milk powders. The highest and lowest ash content were found in SMP with low SCC and WMP with high SCC, respectively. The ash content of SMP was higher when compared with WMP. The current results were in accordance with those of previous studies (Kim et al., 2005; Fitzpatrick et al., 2007; Gaiani et al., 2011).

Water activity, HMF, solubility index, foam stability, dispersibility, wettability, and bulk density of milk powders are given in Table 3. Water activity is one of the most important factors that significantly influence the shelf life of milk powder. Water activity value of milk powders ranged from 0.192 to 0.228, and the mean

value (0.21) was similar to 0.2, which was reported by previous study (Schuck et al., 2007). Whole milk powder samples had higher a_w value than SMP samples containing SCC at the same level. The results showed that a_w increased depending on elevated SCC in both SMP and WMP samples ($P < 0.01$). The increase in a_w of SMP and WMP samples was 0.015 and 0.021, respectively.

The HMF content is an indicator of Maillard reaction. It was revealed from the results that the variation in HMF content of SMP samples was from 1.180 to 1.452 $\mu\text{mol/L}$ and also variation in WMP samples was from 0.715 to 1.086 $\mu\text{mol/L}$. Although SMP contains >700,000 SCC, it had the highest HMF content (1.452 $\mu\text{mol/L}$); WMP contains <300,000 SCC and had the lowest (0.715 $\mu\text{mol/L}$). The results indicate that by increasing SCC, the HMF content was elevated. We noted a correlation between HMF content and a_w ; it was previously reported that Maillard reactions in dry systems generally progress faster at increased a_w .

Table 3. Water activity, hydroxymethylfurfural (HMF), solubility index, foam stability, dispersibility, wettability, and bulk density of milk powders

Sample	Parameter	SCC (cells/mL)		
		<300,000	300,000–700,000	>700,000
Skim milk powder	Water activity	0.213 ± 0.001	0.223 ± 0.004	0.228 ± 0.002
	HMF ($\mu\text{mol/L}$)	1.180 ± 0.032	1.300 ± 0.015	1.452 ± 0.027
	Solubility index (mL)	1.280 ± 0.024	1.424 ± 0.020	1.632 ± 0.056
	Foam stability (min)	11.40 ± 0.76	12.83 ± 0.38	14.92 ± 0.57
	Dispersibility (s)	19.51 ± 0.02	21.16 ± 0.04	23.45 ± 0.06
	Wettability (s)	12.58 ± 0.10	13.50 ± 0.06	15.68 ± 0.14
	Bulk density (g/cm^3)	0.708 ± 0.004	0.692 ± 0.008	0.682 ± 0.006
	Water activity	0.192 ± 0.003	0.207 ± 0.002	0.213 ± 0.04
Whole milk powder	HMF ($\mu\text{mol/L}$)	0.715 ± 0.025	0.891 ± 0.036	1.086 ± 0.020
	Solubility index (mL)	0.940 ± 0.035	0.980 ± 0.028	1.208 ± 0.042
	Foam stability (min)	3.99 ± 0.48	7.60 ± 0.47	9.98 ± 0.95
	Dispersibility (s)	20.50 ± 0.04	23.47 ± 0.12	25.85 ± 0.08
	Wettability (s)	15.90 ± 0.04	17.40 ± 0.08	21.30 ± 0.02
	Bulk density (g/cm^3)	0.685 ± 0.012	0.679 ± 0.008	0.660 ± 0.002

(O'Brien and Morrissey, 1997). Likewise, Pijanowski et al. (1975) reported that HMF content of 6 fresh WMP samples ranged from 2.78 to 7.57 $\mu\text{mol/L}$. In addition, HMF values of WMP were determined initially and were found to range from 1 to 5 $\mu\text{mol/L}$ (Craig et al., 1961). Our results were lower than the previously mentioned reports. Keeney and Bassette (1959) found that high values of HMF were coincident with off-flavors, especially cereal, in the SMP. The lower the HMF content, the more stable the product is.

A high solubility index indicates low solubility. The solubility index of SMP and WMP samples varied from 1.280 to 1.632 and 0.940 to 1.208 mL, respectively. According to our results, WMP samples had higher solubility index than SMP ($P < 0.01$). A positive correlation was observed between SCC and solubility index of milk powders; this might be due to increased HMF content. It was reported that there was a negative correlation between solubility and HMF content (Stapelfeldt et al., 1997). According to standards, SMP and WMP should not have more than 2 and 1.5 mL of sediment for standard grade, respectively (USDA-AMS, 2001a,b). For WMP, a typical solubility index ranges from 0.14 to 1.3 mL (Baldwin and Ackland, 1991; van Mil and Jans, 1991).

The foam stability of SMP and WMP ranged from 11.40 to 14.92 and 3.99 to 9.98 min, respectively. It was found that the foam stability of SMP samples was higher in comparison with WMP. The highest foam stability was determined in SMP containing >700,000 SCC, whereas WMP containing <300,000 SCC had the lowest foam stability. The results showed that SCC positively correlated with foam stability of milk powder samples.

Dispersibility measures how well a milk powder goes into solution under usual home-mixing conditions and, hence, very dispersible powders generally reveal good wettability and are agglomerated with the lack of fine particles (Sharma et al., 2012). Increasing dispersibility time results in decrease of dispersibility feature. The dispersibility feature was found to be negative in WMP samples. These findings were in accordance with those of previous studies (Tuohy, 1989; Tamime, 2009), which reported that the dispersibility of SMP is more than that of WMP. Moreover, elevated SCC adversely affected dispersibility of milk powders. The lowest dispersibility was found in the WMP which contains <700,000 SCC.

The wettability time of SMP and WMP samples ranged from 12.58 to 15.68 and 15.90 to 21.30 s, respectively. It is clear that the wetting time increased with a raise in SCC ($P < 0.01$). The increase in the wetting time of SMP and WMP samples was 3.1 and 5.4 s, respectively. Otherwise, the wettability time of

WMP was higher when compared with that of SMP. Also the maximum wettability time was obtained in the WMP containing <700,000 SCC. The presence of fat on the surface of milk powder increases the hydrophobicity of the surface, decreasing the wettability of the powders (Fäldt and Bergenstahl, 1996). Hygroscopic surface coverage (such as lactose) provides good wetting properties due to the small contact angle (Fäldt and Bergenstahl, 1996; Kim et al., 2002). The SMP wetted in less than 15 s is called instant, whereas no requirement exists for WMP; however, it is advantageous that WMP be wetted in about 30 to 60 s (Kelly et al., 2002). Kim et al. (2002) found that the wetting time of WMP was >15 min.

The bulk density of powders was between 0.660 and 0.708 g/cm^3 . The results indicate that by increasing SCC, the bulk density is reduced all of powder groups ($P < 0.01$). Skim milk powder containing <300,000 SCC had the highest bulk density, whereas the lowest bulk density was found in WMP containing >700,000 SCC. The bulk density of SMP was higher when compared with WMP containing somatic cells at same level. The results were comparable with Fitzpatrick et al. (2004) who reported that bulk density of SMP and WMP was 0.646 and 0.627 g/cm^3 , respectively. Also, Tuohy (1989) reported the packed bulk densities of several milk powders (SMP and WMP) ranged from 0.67 to 0.85 g/cm^3 .

Color values of milk powder samples are presented in Table 4. The L^* values of milk powders significantly affected ($P > 0.01$). Whole milk powders had higher redness value compared with SMP containing SCC at the same level. Depending on increasing SCC, greenness value of both SMP and WMP increased. The increment in greenness value of SMP and WMP was 0.24 and 0.28 units, respectively. The b^* value of SMP and WMP samples varied between 12.73 and 13.07 and 11.83 to 12.35 units, respectively. Increasing SCC significantly affected b^* values of both SMP and WMP. When compared with powders with low SCC, powders containing intermediate and high SCC had higher b^* values. It may relate to increase of HMF content. Previous studies reported that the b^* -value is correlated with the degree of nonenzymatic browning in whey powder (Kneifel et al., 1992).

Scorched particles are undesirable in milk powder; they develop when WMP particles get held up somewhere in the drying process and receive extra heating, causing them to turn a golden brown color (Celestino et al., 1997). Scorched particle disks of milk powders are given in Figure 1. It was found that scorched particles of SMP were higher than comparison with WMP samples. Likewise, scorched particles increased in both SMP and WMP depending on elevated SCC.

Table 4. Color values of milk powders

Sample	Color values ¹	SCC (cells/mL)		
		<300,000	300,000–700,000	>700,000
Skim milk powder	L*	96.03 ± 0.10	96.05 ± 0.06	95.93 ± 0.02
	a*	−3.31 ± 0.03	−3.52 ± 0.08	−3.55 ± 0.00
	b*	12.73 ± 0.08	13.07 ± 0.12	13.07 ± 0.00
Whole milk powder	L*	96.26 ± 0.04	96.27 ± 0.01	96.02 ± 0.06
	a*	−2.64 ± 0.01	−2.83 ± 0.04	−2.92 ± 0.01
	b*	11.83 ± 0.09	12.20 ± 0.05	12.35 ± 0.04

¹L* = lightness, a* = redness, b*= yellowness.

Table 5 and Figure 2 represent particle size measurement and distribution of milk powder samples, respectively. We noted significant differences among milk powder samples ($P < 0.01$). Span is the measurement of the width of the distribution in which the smaller the value the narrower the distribution. Span of SMP and WMP samples varied from 1.390 to 1.351 and 2.582 to 1.428, respectively. Whole milk powder had larger span compared with SMP and also span decreased with the increase in SCC. This is in agreement with the results published by Tuohy (1989), who reported that particle size distribution of WMP was higher than SMP.

Mean particle size D[4,3] of SMP and WMP ranged from 25.587 to 33.544 and 34.109 to 39.849 μm , respectively. The increase on SCC resulted in higher D[4,3]

value of both SMP and WMP, except WMP with high SCC. Whole milk powders had higher mean particle size when compared with SMP.

Uniformity reflects the magnitude of particle size distribution and the gradient of the particle size distribution curve. The lowest and highest values of uniformity were found in SMP with high SCC and WMP with low SCC, respectively. The uniformity value of samples decreased depending on raise in somatic cell. It was reported that the denser the particle size distribution, the closer the uniformity coefficient is to 1(Schuck et al., 2012).

Specific surface area of powder samples changed from 0.241 to 0.426. Although the highest specific surface area was found in SMP containing <300,000 SCC,

Figure 1. Scorched particle disks of skim (SMP) and whole milk powders (WMP). 1 = SMP <300,000 cells/mL; 2 = SMP 300,000–700,000 cells/mL; 3 = SMP >700,000 cells/mL; 4 = WMP <300,000 cells/mL; 5 = WMP 300,000–700,000 cells/mL; 6 = WMP >700,000 cells/mL. Color version available online.

Table 5. Particle size measurement values of milk powders¹

Sample	SCC (cells/mL)	Span	D[4.3] (μm)	Uniformity	Specific surface area	D[3.2] (μm)	$d(0.1)$ (μm)	$d(0.5)$ (μm)	$d(0.9)$ (μm)
Skim milk powder	<300,000	1.390	25.587	0.436	0.426	14.074	5.519	26.921	42.950
	300,000–700,000	1.388	30.019	0.424	0.282	21.277	13.366	27.519	51.570
	>700,000	1.351	33.544	0.396	0.241	24.909	14.921	30.963	56.744
Whole milk powder	<300,000	2.582	35.660	0.798	0.361	16.609	6.669	25.701	73.029
	300,000–700,000	1.646	39.849	0.579	0.256	23.461	15.003	34.091	71.126
	>700,000	1.428	34.109	0.470	0.277	21.669	13.960	31.643	59.132

¹D[4.3] = volume mean diameter; D[3.2] = surface area mean diameter; $d(0.1)$ = 10% of the sample is below this diameter; $d(0.5)$ = 50% of the sample is below this diameter; $d(0.9)$ = 90% of the sample is below this diameter.

WMP containing 300,000 to 700,000 SCC had the lowest value.

The D[3,2] value of SMP and WMP ranged from 14.074 to 24.909 and 16.609 to 23.461 μm , respectively. With higher SCC, D[3,2] value increased in both SMP and WMP samples, except WMP with high SCC.

The $d(0.1)$ was between 5.519 and 15.003 μm ; $d(0.5)$ value of powder samples varied from 25.701 to 34.091 μm . The results showed that WMP had higher mean particle size compared with SMP ($P < 0.01$). No evidence was reported on effect of SCC on particle size of either SMP or WMP. Previous studies reported that mean particle size of SMP and WMP was 53 and 99 μm , respectively (Fitzpatrick et al., 2004) and also the mean particle size $d(0.5)$ varied from 85 (SMP) to 130

μm (WMP; Tuohy, 1989). According to our results, mean particle size results of current study were lower than previous studies.

Texture properties of yogurt produced reconstituted milk powders with SCC are presented in Table 6 and Figures 3 and 4. The firmness of FFY was significantly higher than that of NFY ($P < 0.01$). Depending on increasing SCC, the firmness value of all yogurts decreased. Consistency value of NFY and FFY ranged from 15.271 to 25.061 and 25.148 to 34.926 (N/s), respectively. The increase on SCC resulted in lower consistency value of NFY and FFY, except FFY with high SCC. With an increase in SCC, cohesiveness value of all yogurt groups decreased; also, NFY had higher cohesiveness value when compared with FFY. Rogers

Figure 2. Particle size distribution of milk powders.

Figure 3. Textural properties of nonfat yogurts. Color version available online.

and Mitchell (1994) reported that a negative correlation between yogurt viscosity and SCC in milk. It was reported that lower grades attributed to loss of consistency in a sensory evaluation of high SCC yogurt after 10 to 30 d of storage (Oliveira et al., 2002). On the contrary, Fernandes et al. (2007) showed that high-SCC yogurt presented higher viscosity when compared with low-SCC yogurt.

CONCLUSIONS

This study was conducted to demonstrate for the first time the effects of SCC on the particle size characteristics of the SMP and WMP produced from 3 different SCC. Elevated SCC increased mean particle size of both SMP and WMP, except WMP with high SCC. Depending on increased SCC, span and uniformity of

Figure 4. Textural properties of full-fat yogurts. Color version available online.

Table 6. Textural properties of yogurts produced from reconstituted milk powders

Sample	SCC (cells/mL)	Firmness (N)	Consistency (N/s)	Cohesiveness (N)	Index of viscosity (N/s)
Nonfat yogurt	<300,000	1.001 ± 0.094	25.061 ± 1.123	-0.745 ± 0.055	-1.905 ± 0.161
	300,000–700,000	0.745 ± 0.034	18.889 ± 0.120	-0.551 ± 0.004	-1.444 ± 0.059
	>700,000	0.626 ± 0.054	15.271 ± 0.877	-0.446 ± 0.044	-1.117 ± 0.190
Full-fat yogurt	<300,000	1.674 ± 0.030	34.926 ± 1.001	-0.769 ± 0.052	-1.633 ± 0.098
	300,000–700,000	1.590 ± 0.010	24.173 ± 2.906	-0.559 ± 0.042	-1.268 ± 0.186
	>700,000	1.287 ± 0.111	25.148 ± 0.657	-0.547 ± 0.076	-1.245 ± 0.214

milk powders decreased. The HMF content of powder samples positively correlated with SCC. Increased SCC adversely affected functional properties of milk powders, such as solubility index, dispersibility, and wettability; however, foam stability of powders increased with regard to elevated SCC. We found a positive correlation between scorched particles and SCC. From an industrial point of view, textural properties of yogurts produced from milk powders with somatic cells was adversely affected by increasing SCC.

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