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The Effect of Spray Dryer Atomizer Speed on Casein Micelle Size and Physicochemical Properties of White Cheese

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ABSTRACT: In this research, an industrial spray dryer was used and the effects of atomizer speed on the physicochemical properties of milk powder, the textural and sensory characteristics of white cheese made from this milk powder were evaluated. For this purpose, whole milk was converted into powder by using three different speeds (10,000, 11,000, and 12,000 rpm). The results showed that by increasing atomizer speed in the spray dryer, the average size of casein micelle is significantly decreased ($P < 0.05$), whereas no significant effect is observed on the chemical properties of milk powder. White cheese characteristics indicated that by increasing atomizer speed, texture parameters, such as hardness, mastication, and gumminess were significantly reduced ($P < 0.05$). Sensory evaluation also revealed that the cheese samples prepared with dried milk produced at 12,000 rpm were highly accepted by the panelists. Overall, the findings suggested that 12,000 rpm is the optimal atomizer speed for milk powder production.

Keywords: *Atomizer Speed, Cheese, Milk Powder, Spray Drying, Texture Profile Analysis*.

Introduction

Nowadays, the spray dryer is commonly used in food industries, particularly in dairy. Therefore, the spray dryer output based on milk powder quality produced by dairy industry is highly regarded. The operating temperature does not usually exceed 300 °C, and the particle diameter may measure from10 µm to250µm (Tonon *et al.*, 2008). The use of milk powder as a base material for the production of other food products, as well as features such as easy access, long maintenance, packaging, and transfer because of product volume reduction, had attracted consumers and producers (Chegini and Ghobadian, 2005). Changes in the particle size and properties of casein micelles can affect the properties of dairy products, as well as the colloidal stability and rheological properties (Huppertz *et al.*, 2004). Therefore, information regarding the effect of casein micelle size in the process of enzymatic coagulation and resulting curd characteristics in the cheese industry is particularly important. The effects of high-pressure homogenization and heat treatment process on the characteristics of casein micelles in recombined milk production of skim milk powder were also studied (Sandra and Dalgleish, 2005). Moreover, the effects of high-pressure homogenization on milk characteristics used in cheese production were surveyed (Zamora *et al.*, 2007). Roach and Harte (2008) assayed the damage,

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precipitation, and isolation of casein micelles caused by high-pressure homogenization. Their results showed a reduction in the mean diameter and size of casein micelles. The effects of homogenization pressure and temperature on the textural and micro structural properties of milk-based, creamy dessert products are surveyed (Sohrabvandi *et al.*, 2013). The influences of homogenization pressure (0, 50 and 150bar) before and after heating of textural properties, such as hardness, surface tension and syneresis, were studied. In recent years, research was conducted regarding the changes in casein micelle size under different treatments, as well as the effects of different parameters of the spray dryer on the physicochemical properties of food. Given that few comprehensive and correlative studies on the effect of atomizer speed on the cheese structure are available, the present study aimed to determine the effects of different atomizer speeds (10,000, 11,000, and 12,000 rpm) on the casein micelle size in milk powder and the physicochemical characterization of reconstituted cheese made from this milk.

Materials and Methods

- Preparation of milk powder

Whole milk powder was prepared using spray dryer with type of wheel atomizer and air inlet and product outlet temperatures of 250 °C and 80 °C, respectively, in an industrial zone located in Isfahan, Iran. Outlet products processed using three different wheel atomizer speeds (10,000, 11,000 and 12,000 rpm) identified as A, C, and D, respectively, and the products were kept for future analysis (AOAC, 1996) such as moisture, fat, protein, lactose, ash, pH and casein micelle size (Anema and Li, 2003; Le *et al.*, 2008).

- Casein micelle size by dynamic light scattering

The sizes of casein micelle in whole milk were determined by dynamic light scattering with Malvern Mastersizer 2000 (Malvern Instruments Ltd., Worcestershire, UK). The light source was a 3 mW helium neon laser with a wavelength of 633 nm. Light scattering was detected at a 173°angle, and all measurements were made at 20.0 ± 0.1°C. The process steps are given as follows (Goli *et al.*, 2012a & 2012b; Orlien *et al.*, 2006). 1- Preparation of buffer: Imidazole-calcium buffer contained 20 mM imidazole, 5 mM calcium chloride monohydrate, 30 mM sodium chloride, and 1.5 mM sodium azide. The pH of 1 M hydrochloric acid was adjusted to 6.55. 2- Preparation of skim milk: Up to 1 ml of milk in 1.5 ml plastic tube was placed and centrifuged with acceleration of 25,000*g* for 1 h at 20°C. Subsequently, the supernatant part in the skim milk phase was diluted in imidazole-calcium buffer with a ratio of 1:200. 3- Particle size distribution: It was calculated using statistical software, and all analyses were performed in triplicate order. Standard parameters calculated by the software included volume-weighted average diameter d_{43}, defined as $\Sigma(n_i d_i^4)/\Sigma(n_i d_i^3)$, where n_i is the number of casein micelle of diameter d_i; volume-surface average diameter d_{32}, defined as $\Sigma(n_i d_i^3)/ \Sigma(n_i d_i^2)$; modal diameter corresponding to the population of casein micelle and the most important in volume; specific surface area defined as SSA= $6\varphi/d_{32}$, where φ is the volume fraction of casein micelle; and size distribution width, defined as span = $d_{v0.9}$ - $d_{v0.1}/d_{v0.5}$,where $d_{v0.9}$is the diameter which lies 90% below of casein micelle, and likewise, 10% for $d_{v0.1}$ and 50% for $d_{v0.5}$ (Orlien *et al.*, 2006; Le *et al.*, 2008).

- Preparation of white cheese

Milk powder samples were provided and prepared in liquid form, same as normal milk, and were heated at temperature of 40 °C for 20 min. Acidification was achieved by the in situ production of lactic acid through the fermentation of the milk sugar, lactose, by lactic acid bacteria (bulk culture, 2-3%). Calcium chloride (15 g /100L) was added to the milk, subsequently. Rennet (4g/100L) was also employed (Enzymaks, Inc.). The above mixture was processed for 1.5 h to 2 h at the temperature of 37 °C to form cheese curd. Whey was then removed from the mixture by using a knife before the curd was pressed. Subsequently, the curd was placed in 20% brine for 3 to 4 hours and then in 11% brine at a temperature of 12°C to 14 °C for 4 months (Fox *et al.*, 2017). Cheese samples made from milk were prepared with atomizer speeds of 10,000, 11,000, and 12,000 rpm were identified as A, C, and D, respectively. The cheese sample prepared using whole milk without drying was considered as control sample (B).

- *Texture profile analysis of cheese*

Texture profile analysis (TPA) parameters were determined using a texture analyzer (QTS25, CNS Farnell, UK). A flat cylinder probe with 36 mm diameter was attached to the moving cross head. Cubic samples (20 cm × 20 cm × 20cm) were prepared at 5 °C and immediately compressed to an initial height of 50% (10 mm thickness). The cross head speed was set to 60 $mm.min^{-1}$, and the characteristics of hardness, cohesion, gumminess, and chewiness were measured in each sample. Afterward, penetration test was performed. A flat cylinder probe with 3 mm diameter was applied to the penetration speed of 30 mm min^{-1}. The required force for 10 mm penetration within cheese body was also measured (Fox *et al.*, 2000; Gunasekaran and Mehmet, 2003). The texture values were the means of three replicates tested at each sampling time.

- *Sensory evaluation of cheese*

Eight food science scientists and twenty two students were selected for sensory evaluations under the same conditions of light, temperature, and humidity. For each sample characteristic (taste, texture, appearance, and overall acceptability), scores between 1 and 5 were considered. In this study, parameters were assessed by consumer-oriented and hedonic tests.

- *Statistical analysis*

The results with three replications were tested using SAS software version 9.2 with completely randomized design. The means at 95% level ($p < 0.05$) were compared using Duncan’s test.

Results and Discussion

- *Chemical properties of milk powder*

The dried milk composition results were analyzed by Duncan's test at a significant level of $P<0.05$ and are listed in Table1, in which the atomizer speed showed no significant effect on the chemical properties of milk powder. However, the chemical characteristics of milk samples were almost in their standard range. Significant decrease in pH due to disruption of fat globules and casein micelles had not occurred. Free fatty acids and amino acids were released in the fluid, which can decrease the pH or increase acidity (Birchal *et al.*, 2007; Gebhardt *et al.*, 2006).

Table 1. The Comparison of chemical characteristics mean (±SD) in milk powder processed in three atomizer speed(rpm): 10000(A), 11000(C) and 12000(D)

Speed (rpm)	Lactose (%)	Protein (%)	Fat (%)	Ash (%)	Moisture (%)	pH
10000(A)	38.9±0.6[a]	30.9±0.4[a]	27.26±0.35[a]	5.3±0.2[a]	4.5±0.34[a]	6.66±0.32[a]
11000(C)	39.1±0.5[a]	31.1±0.3[a]	27.53±0.35[a]	5.2±0.2[a]	4.33±0.35[a]	6.43±0.36[a]
12000(D)	39.0±0.3[a]	31.3±0.4[a]	27.93±0.37[a]	5.5±0.2[a]	4.26±0.25[a]	6.16±0.35[a]

Means within a column with different superscripts differ significantly (one-way ANOVA, $P < 0.05$)

- *Casein micelle size*

The casein micelle size measurements during drying are presented in Table 2. Regarding the increase in the atomizer speed, d_{32}, d_{43}, $d_{0.9}$, $d_{0.1}$, and $d_{0.5}$ were significantly reduced ($P < 0.05$), in such a way that the lowest and highest numbers of the parameters in sample D (12,000 rpm) and control sample (blank) were observed, respectively. Increasing the atomizer speed, significantly increased the width of the particle size distribution (span) which used to compare the degree of uniformity of casein micelle size ($P < 0.05$), whereas increasing the speed of the atomizer, had not significant effect on SSA of casein micelle ($P < 0.05$). The changes in parameters of casein micelles caused by the variations in atomizer speed are shown in Table 2. Generally, increasing atomizer speed in the drying process decreased the casein micelle size probably because of increased shear stress in casein micelle membrane. By centrifugal force, fluid milk passed through the center of the wheel and then through the narrow pore wherein the liquid undergoes a sudden pressure. Therefore, shear stress and turbulence resulting in the passage of the nozzle pore enter the liquid particles. Generally, high pressure disrupts hydrophobic and ionic bonds, affecting the stability of casein micelles. Therefore, likely destruction of these bonds, as well as the effect of shear rate and turbulence, causes the breakdown of casein micelles (Sandra and Dalgleish, 2005; Roach and Harte, 2008). Another study also surveyed the effect of high-pressure homogenization on casein micelle and reported that increase in homogenizer pressure decreases the average diameter of casein micelles. Furthermore, Regnault *et al.* (2004) and Anema *et al*. (2006) studied the effect of pressure on phosphocasein at distribution and casein micelle size in raw skim milk at 9 $^{\circ}$C and 20 $^{\circ}$C. They observed that in each temperature, with pressure increase from 100 MPa to 300 MPa, fragmentation of casein micelle and mean particle diameter significantly decreased.

- *Cheese texture profile analysis*

Analysis of variance regarding cheese TPA showed that with increase in atomizer speed from 10,000 rpm to 12,000 rpm, cheese textural properties, such as hardness, linearly are significantly decreased ($P < 0.05$). Cheese with the least hardness, chewiness, and gumminess was related to D (12,000 rpm), whereas most of these properties were related to the control cheese (blank). Additionally, the analysis of variance results showed that atomizer speed did not significantly affect ($P < 0.05$) the rheological parameters, such as cheese springiness and cohesiveness (Table 3). The main influence of the dryer atomizer speed is on the colloidal particles of milk, such as casein micelles and fat globule, because of the effect of shear stress caused by the atomizer nozzle. The pressure initially led to changes in the type and number of carbohydrate-carbohydrate and carbohydrate-protein bonds that can be effective on hardness and cohesiveness of the cheese curd network structure of these particles (Sohrabvandi *et al.*, 2013). Moreover, the increased pressure can lead to creation of pores in the milk colloidal particle structure and destruction of protein-fat globule matrix, which can cause particle size reduction. Consequently, thin-sized fat globule can diffuse into protein matrix and cause softer cheese (Zamora *et al.*, 2007). The results of the research conducted by Sohrabvandi *et al.* (2013) on the effects of homogenization and different pressure on tissue characteristics of milk-based cream dessert showed a decreasing trend in firmness, with increasing homogenization pressure prior to the thermal process. In another study, the influence of high-pressure homogenization on cow's milk for cheese production was analyzed, and increasing pressure because of the weakening of gel structure reduced the clot firmness (Zamora *et al.*, 2007).

- Sensory evaluation of cheese

The analysis of variance results presented in Table 4 showed no significant difference among the mean scores in sensory evaluations of textural, appearance, and overall acceptability of cheese samples ($P < 0.05$). Generally, all sensory evaluation parameters containing texture, appearance, and overall acceptability in cheese samples D (12,000 rpm) presented the highest average scores from the evaluators, whereas the control cheese samples (blank) received the lowest ones. The better appearance and more uniform texture are probably attributed to a decrease in casein micelles size. However, the analysis of variance mean scores were not significantly different in taste sensory evaluation.

Conclusion

The results showed that the changes in atomizer speed did not significantly affect the chemical properties of produced milk. However, increasing the atomizer speed from 10,000 rpm to 12,000 rpm caused, significant decreasing in d_{32}, d_{43}, $d_{0.9}$, $d_{0.1}$, and $d_{0.5}$ and significant increasing in spam ($P < 0.05$), without having a significant change on SSA (P > 0.05). The Texture Profile Analysis of cheese showed that,

Table 2. The comparison of casein micelle size mean (±SD) in raw milk (Blank) and reconstituted milk powder processed with three different atomizer speed (rpm): 10000(A), 11000(C) and 12000(D)

Speed(rpm)	$d_{0.9}$(mm)	$d_{0.5}$ (mm)	$d_{0.1}$ (mm)	d_{43} (mm)	d_{32} (mm)	SSA (m^2/g)	Span
10000(A)	373.3±10.1^a	253.3±6^a	216.3±5.5^a	324.6±12^a	261.6±8.1^a	23.6±3.7^a	365±5.6^c
11000(C)	350.3±9.6^b	252±6^a	215.3±6^a	295.3±10^b	241±11^b	24.8±2.1^a	435.6±8.1^b
12000(D)	306.6±4.5^c	226±6.1^b	160.6±11^b	254.3±8.3^c	227±8.1^b	25.1±2.3^a	465±1^a
Blank(B)	375±12.4^a	258.3±5.5^a	219.6±5^a	326.3±12^a	263.6±8^a	22.8±2.1^a	360.6±5.1^c

Means within a column with different superscripts differ significantly (one-way ANOVA, $P < 0.05$)

Table 3. The Texture Profile Analysis mean (±SD) of Cheese prepared with the raw milk (Blank) and reconstituted milk powder processed with three different atomizer speed (rpm): 10000(A), 11000(C) and 12000(D)

Speed (rpm)	Springiness (mm)	Cohesiveness	Gumminess (g)	Chewiness (N.mm)	Hardness (N)
10000(A)	6.27±0.07^a	0.496±0.05^a	21.21±2.68^a	136.56±6.76^a	45.3±1.51^a
11000(C)	6.34±0.06^a	0.443±0.08^a	12.88±3.93^b	82.66±6.45^b	27.21±2.15^b
12000(D)	6.39±0.06^a	0.426±0.06^a	11.69±0.96^b	71.22±1.52^c	25.66±1.75^b
Blank(B)	6.25±0.09^a	0.523±0.05^a	23.09±1.98^a	144.07±5.92^a	46.76±3.35^a

Means within a column with different superscripts differ significantly (one-way ANOVA, $P < 0.05$)

Table 4. The sensory evaluation mean (±SD) of Cheese prepared with the raw milk (Blank) and reconstituted milk powder processed with three different atomizer speed (rpm): 10000(A), 11000(C) and 12000(D)

Speed (rpm)	overall Acceptability	Appearance Acceptability	Texture Acceptability	Taste Acceptability
10000(A)	0.46^c±3.25	0.46^b±3.25	0.46^c±3.25	0.35^a±3.87
11000(C)	0.53^b±4	0.35^a±4.12	0.46^b±4.25	0.46^a±3.75
12000(D)	0.51^a±4.37	0.53^a±4.5	0.46^a±4.75	0.35^a±3.87
Blank(B)	0.35^c±3.12	0.53^b±3	0.35^c±3.12	0.51^a±3.62

Means within a column with different superscripts differ significantly (one-way ANOVA, $P < 0.05$)

increasing the atomizer speed from 10,000 rpm to 12,000 rpm caused, significant decreasing in parameters of hardness, chewiness, and gumminess ($P < 0.05$). The atomizer speed had no significant effect on the elasticity (Springiness) and cohesiveness of the cheese samples. Sensory evaluation results indicated greatest acceptance for cheese D (12,000 rpm) from the panelists that is the highest average score appearance in terms of texture, appearance, and overall acceptability. Therefore considering the lack of chemical changes in dried milk, casein micelles in dried milk have more uniform and textural characteristics and sensory evaluation in white cheese sample have improved. In conclusion, increasing the spray dryer atomizer speed up to 12,000 rpm can produce better results in the production of cheese from reconstituted dried milk.

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