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The effects of microfluidization on the physical, microbial, chemical, and coagulation properties of milk

A. J. Bucci,[1] D. L. Van Hekken, M. H. Tunick,[2] J. A. Renye, and P. M. Tomasula
Eastern Regional Research Center, Dairy & Functional Foods Research Unit, USDA, Agricultural Research Service (ARS), Wyndmoor, PA 19038

ABSTRACT

This work examines the use of mild heat treatments in conjunction with 2-pass microfluidization to generate cheese milk for potential use in soft cheeses, such as Queso Fresco. Raw, thermized, and high temperature, short time pasteurized milk samples, standardized to the 3% (wt/wt) fat content used in cheesemaking, were processed at 4 inlet temperature and pressure conditions: 42°C/75 MPa, 42°C/125 MPa, 54°C/125 MPa, and 54°C/170 MPa. Processing-induced changes in the physical, chemical, and microbial properties resulting from the intense pressure, shear, and cavitation that milk experiences as it is microfluidized were compared with nonmicrofluidized controls. A pressure-dependent increase in exit temperature was observed for all microfluidized samples, with inactivation of alkaline phosphatase in raw and thermized samples at 125 and 170 MPa. Microfluidization of all samples under the 4 inlet temperature and processing pressure conditions resulted in a stable emulsion of fat droplets ranging from 0.390 to 0.501 μm, compared with 7.921 (control) and 4.127 (homogenized control) μm. Confocal imaging showed coalescence of scattered fat agglomerates 1 to 3 μm in size during the first 24 h. We found no changes in fat, lactose, ash content or pH, indicating the major components of milk remained unaffected by microfluidization. However, the apparent protein content was reduced from 3.1 to 2.2%, likely a result of near infrared spectroscopy improperly identifying the micellar fragments embedded into the fat droplets. Microbiology results indicated a decrease in mesophilic aerobic and psychrophilic milk microflora with increasing temperature and pressure, suggesting that microfluidization may eliminate bacteria. The viscosities of milk samples were similar but tended to be higher after treatment at 54°C and 125 or 170 MPa. These samples exhibited the longest coagulation times and the weakest gel firmness, indicating that formation of the casein matrix, a critical step in the production of cheese, was affected. Low temperature and pressure (42°C/75 MPa) exhibited similar coagulation properties to controls. The results suggest that microfluidization at lower pressures may be used to manufacture high-moisture cheese with altered texture whereas higher pressures may result in novel dairy ingredients.
Key words: milk, microfluidization, homogenization

INTRODUCTION

Of the 14.4 billion liters of fluid milk sold in the United States in 2016, 99.99% was pasteurized (DMI, 2017). The US FDA (2017) states that milk is legally pasteurized when heat treated at 72°C for 15 s (HTST), ensuring that the fastest moving particles meet the time and temperature combination, eliminating pathogenic bacteria and significantly reducing spoilage microflora. To address food security concerns, commercial HTST systems are often operated in excess of 75°C and hold times of 18 s (Tomasula and Kozempel, 2004). However, as the severity of heat treatment increases, changes may also occur in the dairy product quality related to color, flavor, and protein stability (Van Boekel, 1998). As a result, scientists are exploring alternative mechanisms to produce high-quality, safe, dairy products. One approach uses high pressure to eliminate pathogens and reduce spoilage microflora.

High-pressure techniques have been explored to assess their effects on specific milk components (Mohan et al., 2016) as well as in the manufacture of dairy products, including Queso Fresco (Tomasula et al., 2014), yogurt (Ciron et al., 2012), and cheddar cheese (Devi et al., 2013). High-pressure processing methods may be operated in a batch or continuous fashion. High hydrostatic pressure, a batch process, has been used to eliminate dairy pathogens, including *Escherichia coli* (Styles et al., 1991), *Listeria monocytogenes* (Erkmen and Karataş, 1997), and *Staphylococcus aureus* (Patterson, 2005). However, batch processing is typically not

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[1] Corresponding author: Anthony.Bucci@ars.usda.gov
[2] Current address: Drexel University, Department of Culinary Arts and Food Science, 3141 Chestnut Street, Philadelphia, PA 19104.

practical for production of large volumes of milk-based dairy products.

Continuous high-pressure techniques may employ high-pressure homogenization valves or microfluidization. Using high-pressure homogenization valves, the inlet temperature and total pressure are key parameters to identify. Paired with the near instantaneous increase in temperature inside the homogenizer, the combined mechanical and thermal effects produce a pasteurization-like treatment (Dumay et al., 2013). In microfluidization, a stream of product enters a specially designed impact chamber with fixed geometry microchannels. Similar to high-pressure homogenization valves, the key parameters include inlet temperature, microfluidizing pressure, and number of passes. Inside the impact chamber, the stream splits, accelerating its velocity and greatly increasing the pressure. The 2 streams then collide with a combination of shear, cavitation, and turbulence eliminating pathogens, reducing spoilage microflora, and homogenizing the product. In the case of milk, microfluidization also removes the milk fat globular membrane, fractionates casein micelles, reduces the size of lipid droplets, and embeds casein fragments onto the surface of the newly formed lipid droplets (Dalgleish et al., 1996; Ciron et al., 2011).

The primary objective of our work was to examine the effects of 4 microfluidization temperature and pressure combinations on 3.0% milk. Changes in physical, microbial, chemical, and coagulation properties were compared with both 2-stage homogenized and nonhomogenized controls. The results suggested that low microfluidization pressures may be useful in the production of high-moisture cheese, whereas higher pressures can be used for novel dairy ingredients.

MATERIALS AND METHODS

Milk

Three shipments of approximately 208 L of raw milk and 3.8 L of raw heavy cream were procured from local dairies and standardized to 3.0% fat at the ERRC Dairy & Functional Foods Research Unit dairy processing facilities in Wyndmoor, Pennsylvania, over a 6-wk period. The standardized milk was divided into thirds, with one portion immediately refrigerated at 4°C until microfluidized. The remaining milk was heat treated using HTST or thermization.

Processing

Heat Treatments. Heat treatments were performed using pilot-scale processing equipment. Milk was treated using a Universal Pilot Plant (**UPP**; Waukesha Cherry-Burrell, Delavan, WI) or Armfield UHT/HTST Heat Exchanger system (FT74XTS, Armfield Limited, Ringwood, UK).

After reaching thermization conditions of 65°C for 15 s, one portion of the milk was processed. The product stream was then cooled to 25°C (UPP) or 20°C (Armfield UHT/HTST Heat Exchanger system) and collected into 19-L milk cans. Full cans were immediately returned to refrigeration at 4°C until microfluidized. Product flow rates were 40 L/h on the Armfield UHT/HTST Heat Exchanger system and 113 L/h on the UPP.

The remaining portion was HTST treated at 75°C for 15 s. All other processing conditions were identical to thermization. Three liters each of raw, thermized, and HTST-treated milk were then warmed to 45°C to liquefy the milk fat,and homogenized using a 2-stage process (10 MPa/5 MPa). Milk processed on the UPP was homogenized using a Gaulin labor-homogenizer lab 60/100 (SPX Flow Technology, Charlotte, NC), whereas milk treated on the Armfield UHT/HTST Heat Exchanger System was homogenized with a Niro Soavi NS2001 H (GE, Dusseldorf, Germany).

Microfluidization. Figure 1 shows a schematic of the microfluidization process. High-pressure processing was carried out using a Microfluidizer (M210-E/H; Microfluidics Corp., Westwood, MA). The inlet feed was supplied via a Tri-Clover PR3 positive displacement pump (Alfa-Laval, Warminster, MA) with polymer lobes and gravity fed with a 7.5-L hopper. An inlet pressure of 345 kPa was maintained throughout testing. The hopper temperature was kept approximately 3 to 4°C warmer to account for heat transfer losses in the piping during flow. Hopper temperature was measured using a thermometer probe, whereas a K-type pipe clamp thermocouple (Grainger, Lake Forest, IL) connected to a temperature logger (HH309A, Omega Engineering, Stamford, CT) monitored the impact chamber inlet temperature.

Preliminary runs were performed using inlet temperatures of 10, 42, and 54°C at 34, 75, 100, 125, 150, and 170 MPa and 5 passes. No appreciable particle size reduction was observed after the second pass. It was also not possible to maintain an impact chamber inlet temperature of 10°C due to the temperature increase from pumping milk through the microfluidizer. At 34 MPa, the processing time became prohibitively long, making the lowest practical pressure 75 MPa. Pressures greater than 100 MPa resulted in microbial reduction, and at 125 MPa and 42 or 54°C the exit temperatures averaged 69 and 76°C, respectively. The highest pressures, 150 and 170 MPa, yielded conditions that could denature β-LG, reaching over 85°C at 170 MPa. Lastly, 170 MPa was the highest pressure achievable on the