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Research Note

Comparative Effects of Ohmic and Conventional Heating for Inactivation of *Escherichia coli* O157:H7, *Salmonella enterica* Serovar Typhimurium, and *Listeria monocytogenes* in Skim Milk and Cream

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ABSTRACT

Ohmic heating has proven advantages over conventional thermal processing and novel thermal alternative technologies. In this study, the effect of ohmic and conventional heating for pasteurizing skim milk and cream was examined. All treatment conditions for ohmic and conventional heating were identical except for composition of the heating chamber. In most cases, the reduction of three pathogens did not differ significantly between ohmic heating and conventional heating at fixed treatment temperatures and times. However, temperature can be increased more rapidly with ohmic than with conventional heating treatment, both in skim milk and in cream. Therefore, *E. coli* O157:H7, *Salmonella* Typhimurium, and *L. monocytogenes* were inactivated more effectively by ohmic heating treatment for the same treatment time intervals. Also, the time required for pathogen populations to decrease to below the detection limit was less for ohmic heating than conventional heating. Quality aspects (viscosity, pH, and color) of skim milk and cream suffered less degradation by ohmic than by conventional heating. Although there was little evidence of a nonthermal effect of ohmic heating, the results demonstrate significant advantages in the use of ohmic heating over conventional methods for pasteurizing skim milk and cream.

Milk is consumed worldwide because of its high nutritional value. Although milk is pasteurized prior to distribution, concerns remain about the microbiological safety of milk products. Foodborne pathogens are commonly detected in raw milk and dairy farm environmental samples. Based on an assay of farm environmental samples, 3.76% of all isolates were *Salmonella,* 6.51% *L. monocytogenes,* and 0.72% *E.coli* O157:H7 *(11).* These findings indicate that foodborne pathogens, including *E. coli* O157:H7, *Salmonella,* and *Listeria monocytogenes,* may be potential biohazards in milk and other dairy products.

Outbreaks have been traced to pasteurized milk. In the United States from 1998 to 2014, nine outbreaks associated with fluid milk were reported, resulting in 2,200 illnesses, including three deaths *(16).* The Centers for Disease Control and Prevention (CDC) reported pasteurized milk–related outbreaks involving *Salmonella* Typhimurium in 2000 and 2002. The CDC also reported pasteurized milk–related outbreaks associated with *Listeria monocytogenes,* resulting in three deaths in 2007 *(3).* Some contributing factors in pasteurized milk–related outbreaks include inadequate pasteurization and postpasteurization contamination *(12).*

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High-temperature, short-time treatment (HTST) is recommended by the U.S. Food and Drug Administration for pasteurizing milk. Until now, plate heat exchangers have been used extensively for dairy and other food processing industries. They exhibit excellent heat transfer characteristics that allow for more compact designs than are achievable with conventional shell and tube heat exchangers *(1).* Plates are usually manufactured from stainless steel as their standard material. However, HTST pasteurization has serious limitations, including emissions of greenhouse gas, high water consumption, and a high production cost. Tomasula et al. *(20)* used a computer simulation method to study energy consumption and water use in a fluid milk plant. They estimated $0.507/liter of unit production cost and 0.245 kg of water per kg of raw milk processed for HTST processing. Moreover, some research revealed that high concentrations of *L. monocytogenes* can survive HTST pasteurization *(7).* These results indicate that conventional HTST pasteurization is not sufficient to inactivate all foodborne pathogens in milk. Therefore, a more effective technology is needed to ensure HTST pasteurization of raw milk.

Ohmic heating is a novel technology that uses an electric field to increase temperature of a food sample. Ohmic heating has proven advantages over conventional

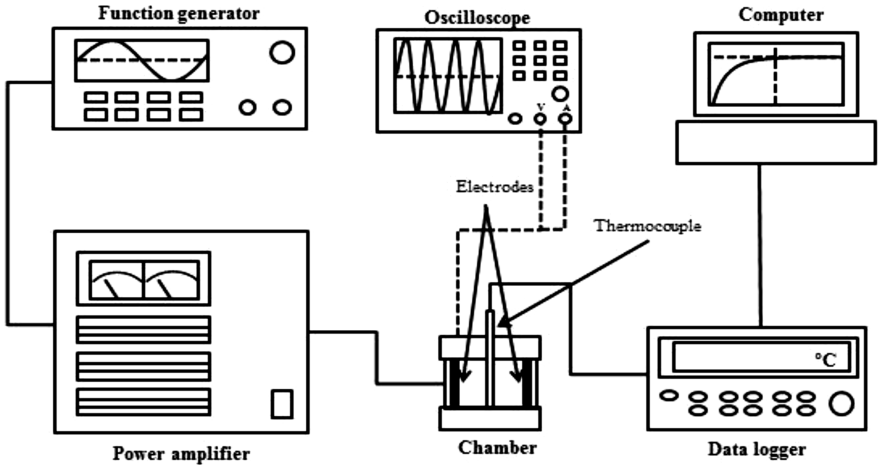

FIGURE 1. *Schematic diagram of the ohmic heating system at Seoul National University (Seoul, Korea).*

thermal processing and novel thermal alternative technologies such as microwave heating, radio frequency heating, and induction heating. Better product quality, shorter heating time, lower capital cost, better energy efficiency, and an environmentally friendly process are the key advantages *(21)*. In the 1990s, the development of a new high-frequency (25 to 30 kHz) power supply, which included a signal with an impulsive waveform (period: 40 μs), a modular design, and full-bore electrodes made of stainless steel or titanium (all of which lowered costs), spawned a ''second generation'' of ohmic processing equipment, providing improved quality results at reduced expense *(15)*. In addition to rapid heating, some studies have reported nonthermal effects of ohmic heating in milk *(18)* and in apple juice, in which it inactivated *E. coli* O157:H7, *Salmonella* Typhimurium, and *Listeria monocytogenes (14)*.

To our knowledge, no previous studies have compared ohmic heating with conventional heating involving stainless steel plates. Therefore, the conventional heating chamber in the present study was made of stainless steel of the same size and form as the ohmic heating chamber. This study investigated how rapidly ohmic heating can increase temperature compared with conventional heating and how rapidly it can inactivate foodborne pathogens in skim milk and cream. We also examined the effect of each heating treatment on quality attributes, such as viscosity, color, and pH.

MATERIALS AND METHODS

Bacterial cultures and cell suspension. Three strains each of *E. coli* O157:H7 (ATCC 35150, ATCC 43889, and ATCC 43890), *Salmonella* Typhimurium (ATCC 19585, ATCC 43971, and DT 104), and *L. monocytogenes* (ATCC 19111, ATCC 19115, and ATCC 15313) were obtained from the bacterial culture collection of the School of Food Science, Seoul National University (Seoul, South Korea). Three strains of *E. coli* O157:H7 were isolated from human feces. *Salmonella* Typhimurium ATCC 43971 was derived from an existing strain. *L. monocytogenes* strains ATCC 19111, 19115, and 1535 were isolated from poultry, human, and rabbit, respectively. Cultures were produced as follows: a single colony cultivated from frozen stocks on tryptic soy agar (Difco, BD, Sparks, MD) was inoculated into 5 ml of tryptic soy broth (Difco, BD), incubated at 37°C for 24 h, collected by centrifugation at 4,000 × *g* for 20 min at 4°C, and washed three times with 0.2% peptone water (Bacto Peptone, Difco, BD). The final pellets were resuspended in 0.2% peptone water, corresponding to approximately 10^8 to 10^9 CFU/ml. Afterward, suspended pellets of the three pathogens were combined to comprise a mixed culture cocktail containing approximately equal numbers of cells of each strain of *E. coli* O157:H7 (10^7 CFU/ml), *Salmonella* Typhimurium (10^7 CFU/ml), and *L. monocytogenes* (10^6 CFU/ml).

Sample preparation and inoculation. Pasteurized skim milk (pH 6.6) and sterilized cream (milk cream, 99.6%) were purchased from a local grocery store (Seoul, South Korea). Skim milk and cream were stored under refrigeration (~4.0°C) and, 1 h prior to inoculation, were removed and allowed to equilibrate to room temperature (22 ± 1°C). A mixed-culture cocktail (0.2 ml) was inoculated into 25 ml of skim milk and cream before treatment at room temperature.

Ohmic heating system. Ohmic heating treatments were carried out in a previously described apparatus *(9)*. The ohmic heating system (Fig. 1) consisted of a function generator (catalog no. 33210A, Agilent Technologies, Palo Alto, CA), a precision power amplifier (catalog no. 4510, NF Corp., Yokohama, Japan), a two-channel digital-storage oscilloscope (catalog no. TDS2001C, Tektronix, Inc., Beaverton, CO), a data logger (catalog no. 34970A, Agilent Technologies), and an ohmic heating chamber. The function generator produced various waveforms at frequencies from 1 mHz to 10 MHz and a maximum output level of 5 V. The signals generated through the power amplifier were amplified up to a maximum output of 141 V of alternating current. The two-channel digital storage oscilloscope was used to measure signals, including waveform, frequency, voltage, and current. K-type thermocouples were inserted at the center of the ohmic heating chamber, and temperature was controlled by Labview software (National Instrument, Austin, TX). The distance between the two electrodes was 2 cm, and the cross-sectional area was 60 cm^2.

Ohmic heat treatment. For all ohmic treatments, a 20-kHz frequency and sine waveform were used. Twenty-five milliliters of sample was placed into the ohmic heating chamber. For fixed-temperature experiments, the electric field strength was fixed at 9.6 V/cm after reaching the target temperature. The function generator operated according to whether the target temperature was reached or not. A mixed-culture cocktail (0.2 ml) was inoculated into 25 ml of sample after reaching target temperatures. Treatments were conducted at 55, 60, 65, and 70°C for 1 min. For experiments corresponding to temperature history, a mixed-culture cocktail (0.2 ml) was inoculated into 25 ml of sample before treatment. The final temperature was fixed at 71.5 and 82°C for skim milk and cream, respectively. The ohmic heating electric field was regulated

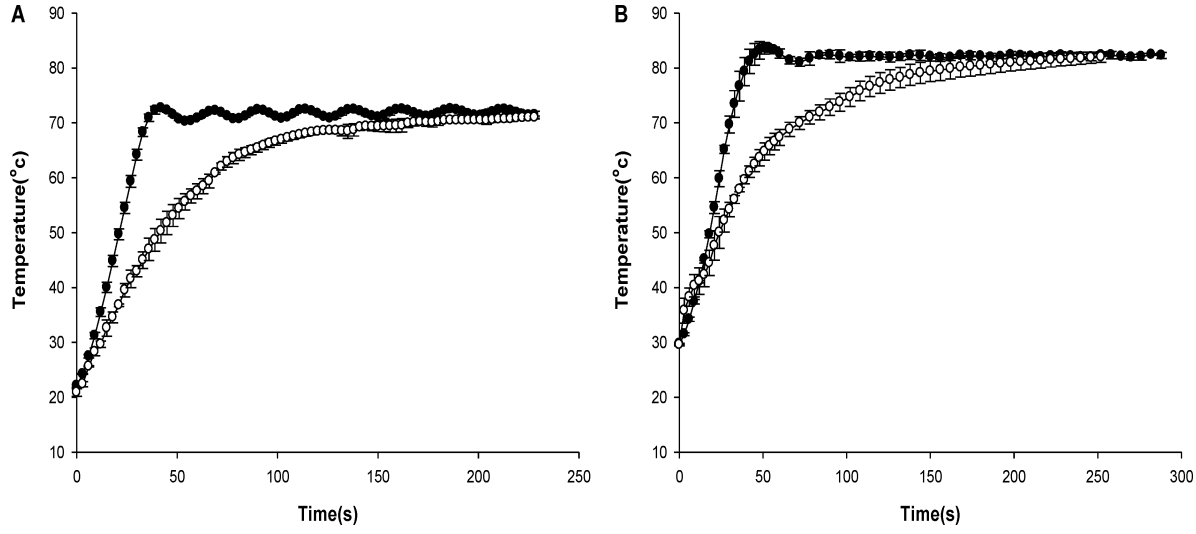

FIGURE 2. *Temperature history of skim milk (A) and cream (B) treated with ohmic (●) and conventional (○) heating. The results are means from three experiments, and error bars indicate standard errors.*

and ranged from 9.6 to 32 V/cm to obtain temperature histories shown in Figure 2. Times to reach final temperature for skim milk and cream were 40 and 50 s, respectively. Skim milk was treated for 0, 10, 20, 30, 40, 50, and 60 s. Cream was treated for 0, 20, 40, 60, 80, 100, 120, and 140 s. All other conditions were same as those described above for fixed temperature.

Conventional heat treatment. For all conventional experiments, a constant-temperature water bath (BW-10G, Jeio Tech, Seoul, South Korea) was used. The conventional heating chamber was made of stainless steel (2 by 15 by 6 cm) of 0.2-cm thickness. Twenty-five milliliters of sample was placed into the conventional heating chamber. A fiber optic temperature sensor (FOT-L, FISO Technologies Inc., Quebec, Canada) connected to a signal conditioner (TMI-4, FISO Technologies Inc.) was used to measure the temperature in the middle of the sample. For fixed-temperature experiments, the temperature of the constant-temperature water bath was set 2°C higher than the target. Treatments were conducted at 55, 60, 65, and 70°C for 1 min. For conventional heating corresponding to temperature history, the temperature of the water bath was fixed at 74.5 and 85°C for skim milk and cream, respectively. These temperatures were selected based on preliminary experiments in which the final sample temperature reached 71.5 and 82°C for skim milk and cream, respectively. To reach the final temperature required 210 and 240 s for skim milk and cream, respectively. Skim milk was treated for 0, 30, 60, 90, 120, 150, 180, and 210 s. Cream was treated for 0, 30, 60, 90, 120, 150, 180, 210, and 240 s. All other conditions were the same as those described above for fixed temperature.

Microbial enumeration. For microbial enumeration, each treated 25-ml sample was immediately transferred into a sterile stomacher bag (Labplas, Inc., Sainte-Julie, Quebec, Canada) containing 225 ml of 0.2% peptone water and was homogenized for 2 min with a stomacher (Easy Mix, AES Chemunex, Rennes, France). After homogenization, 1-ml aliquots withdrawn from stomacher bags were 10-fold serially diluted in 0.2% peptone water, and 0.1-ml aliquots of appropriate diluents were spread plated onto each selective medium. Sorbitol MacConkey agar, xylose lysine deoxycholate agar, and Oxford agar base with Bacto Oxford antimicrobial supplement (all from Difco) were used as selective media for enumeration of *E. coli* O157:H7, *Salmonella* Typhimurium, and *L. monocytogenes,* respectively. Where low levels of surviving cells were expected, 1-ml aliquots withdrawn from stomacher bags were divided between four plates of each medium and were spread plated. After all the plates were incubated at 37°C for 24 to 48 h, colonies were counted.

Color, pH, and viscosity measurement. For color, pH, and viscosity measurements, each heating treatment was performed at the maximum treatment time, and an untreated sample was used as the control. For skim milk, the heating times were 60 and 210 s for ohmic and conventional heating, respectively. For cream, the heating times were 140 and 240 s for ohmic heating and conventional heating, respectively. The pH of treated and untreated samples was measured with a Seven Multi 8603 pH meter (Mettler Toledo, Greifensee, Switzerland). The color of treated and untreated samples was measured using a Minolta colorimeter (CR400, Minolta Co., Osaka, Japan). Color values for L*, a*, and b* (lightness, redness, and yellowness, respectively) were recorded to evaluate color changes of treated and untreated samples. Sample viscosity was determined using a Brookfield viscometer (model DV-II+ Pro, Brookfield Engineering Laboratories, Boston, MA), with a SC4-18 spindle at 100 rpm at 22.5 $\pm$ 1°C used to determine the viscosity of skim milk and a SC4-34 spindle at 60 rpm at 18.2 $\pm$ 1°C used to determine the viscosity of cream.

Statistical analysis. All experiments were duplicate plated and replicated three times. All data were analyzed by the analysis of variance procedure of the Statistical Analysis System (SAS Institute, Cary, NC), and mean values were separated using Duncan's multiple-range test. Significant differences in the processing treatments were determined at a significance level of $P = 0.05$.

RESULTS

Comparison of the effect of ohmic and conventional heating on inactivation of *E. coli* O157:H7, *Salmonella* Typhimurium, and *L. monocytogenes* at fixed temperatures. Survival data for *E. coli* O157:H7, *Salmonella* Typhimurium, and *L. monocytogenes* in skim milk and cream subjected to ohmic and conventional heating are shown in Table 1. In the case of skim milk, *E. coli* O157:H7, *Salmonella* Typhimurium, and *L. monocytogenes*

TABLE 1. *Survival of* E. coli *O157:H7,* Salmonella *Typhimurium, and* L. monocytogenes *in skim milk and cream treated at different temperatures for 1 min*[a]

			Population (log CFU/ml) at different temps			
		Control	55°C	60°C	65°C	70°C
Skim milk	*E. coli* O157:H7	OH 6.73 ± 0.46 A	6.26 ± 0.31 A	5.47 ± 0.55 A	1.77 ± 0.68 A	<1.00 A
		CONV 6.77 ± 0.40 A	6.74 ± 0.22 A	6.50 ± 0.11 B	3.08 ± 0.59 A	<1.00 A
	Salmonella Typhimurium	OH 6.69 ± 0.26 A	5.60 ± 0.02 A	4.03 ± 0.74 A	<1.00 A	<1.00 A
		CONV 6.70 ± 0.24 A	6.03 ± 0.67 A	5.45 ± 0.42 B	1.20 ± 0.35 A	<1.00 A
	L. monocytogenes	OH 5.60 ± 0.10 A	4.75 ± 0.26 A	4.11 ± 0.73 A	<1.00 A	<1.00 A
		CONV 5.67 ± 0.06 A	5.20 ± 0.17 A	5.15 ± 0.12 A	3.65 ± 0.28 B	1.00 ± 0.58 A
Cream	*E. coli* O157:H7	OH 6.72 ± 0.54 A	6.50 ± 0.24 A	6.08 ± 0.67 A	5.24 ± 0.28 A	4.36 ± 0.56 A
		CONV 6.79 ± 0.43 A	6.76 ± 0.23 A	6.06 ± 0.48 A	5.51 ± 0.46 A	4.42 ± 0.37 A
	Salmonella Typhimurium	OH 6.55 ± 0.42 A	5.68 ± 0.27 A	5.04 ± 0.83 A	3.26 ± 0.25 A	4.11 ± 0.39 A
		CONV 6.47 ± 0.40 A	5.96 ± 0.90 A	5.02 ± 0.93 A	3.75 ± 0.10 B	3.92 ± 0.18 A
	L. monocytogenes	OH 5.84 ± 0.06 A	5.16 ± 0.40 A	4.64 ± 0.14 A	4.11 ± 0.34 A	2.74 ± 0.73 A
		CONV 5.89 ± 0.14 A	5.52 ± 0.14 A	5.04 ± 0.19 B	4.32 ± 0.26 A	3.42 ± 0.07 A

[a] Values are expressed as mean ± standard deviation. Values in the same column for each pathogen that are followed by the same letter are not significantly different ($P > 0.05$). OH, ohmic heating; CONV, conventional heating.

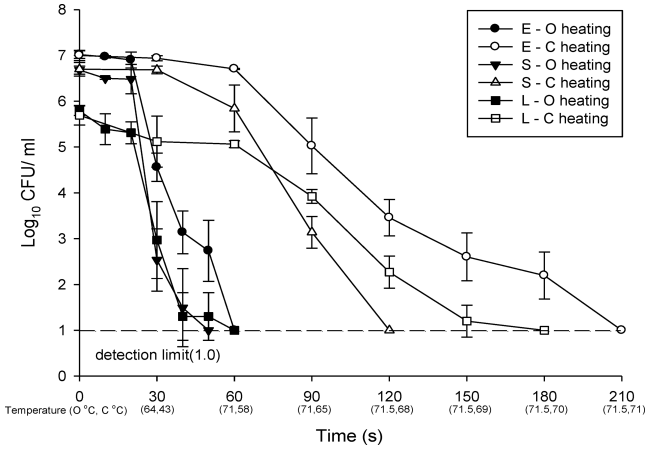

FIGURE 3. *Survival curves of* E. coli *O157:H7 (E),* Salmonella *Typhimurium (S), and* L. monocytogenes *(L) corresponding to microbial inactivation by ohmic (O) and conventional (C) heating in skim milk. End-point temperatures (ohmic heating, conventional heating) after each treatment are represented. The results are means from three experiments, and error bars indicate standard errors.*

were inactivated more effectively by ohmic heating than by conventional heating at 60 and 65°C. In the case of cream, *Salmonella* Typhimurium and *L. monocytogenes* were inactivated more effectively by ohmic heating than by conventional heating at 60 and 65°C. However, in most cases, the reductions of the three pathogens did not significantly differ between ohmic and conventionally treated samples.

Temperature history of skim milk and cream treated by ohmic and conventional heating. The temperature history of skim milk and cream subjected to ohmic and conventional heating is shown in Figure 2. For both skim milk and cream, temperature increased more rapidly when treated with ohmic than with conventional heating. Reaching the target temperature (71.5°C) required 40 and 210 s when skim milk was treated with ohmic and conventional heating, respectively. Times required for cream to reach the target temperature (82°C) were 50 and 240 s for ohmic and conventional heating, respectively.

Comparison of the effect of ohmic and conventional heating on inactivation of *E. coli* O157:H7, *Salmonella* Typhimurium, and *L. monocytogenes* in skim milk corresponding to temperature histories. The survival of *E. coli* O157:H7, *Salmonella* Typhimurium, and *L. monocytogenes* in skim milk treated with ohmic and conventional heating corresponding to temperature histories is shown in Figure 3. Regardless of pathogen, ohmic heating achieved greater reduction than conventional treatment for the same treatment time intervals. The time required for *E.coli* O157:H7 to decrease to below the detection limit was 60 s for ohmic and 210 s for conventional heating. The time required for *Salmonella* Typhimurium to decrease to below the detection limit was 50 s for ohmic and 120 s for conventional heating. Finally, 60 and 180 s were necessary to reduce *L. monocytogenes* to

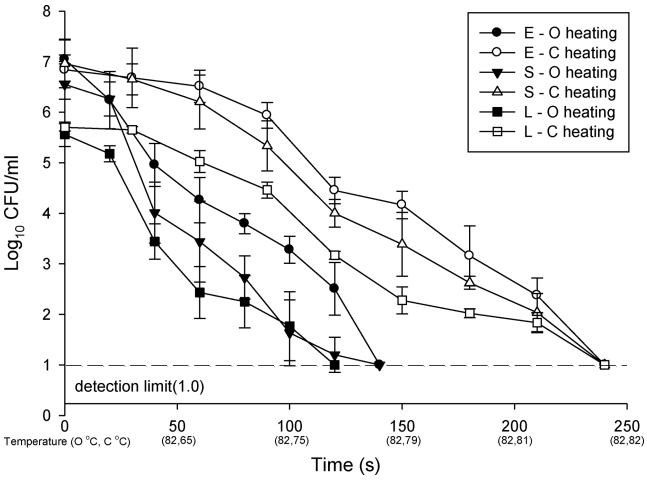

FIGURE 4. *Survival curves of* E. coli *O157:H7 (E),* Salmonella *Typhimurium (S), and* L. monocytogenes *(L) corresponding to microbial inactivation by ohmic (O) and conventional (C) heating in cream. End-point temperatures (ohmic heating, conventional heating) after each treatment are represented. The results are means from three experiments, and error bars indicate standard errors.*

below the detection limit using ohmic and conventional heating, respectively.

Comparison of the effect of ohmic and conventional heating on inactivation of *E. coli* O157:H7, *Salmonella* Typhimurium, and *L. monocytogenes* in cream corresponding to temperature histories. The survival of *E. coli* O157:H7, *Salmonella* Typhimurium, and *L. monocytogenes* in cream treated with ohmic and conventional heating corresponding to temperature histories is shown in Figure 4. Regardless of the pathogen, ohmic heating achieved significantly greater reduction than conventional heating at the same treatment time intervals. For both *E. coli* O157:H7 and *Salmonella* Typhimurium, 140 and 240 s were needed to decrease these pathogens to below the detection limit using ohmic and conventional heating, respectively. Lastly, 120 and 240 s were required for *L. monocytogenes* to be reduced to below the detection limit for ohmic and conventional heating, respectively.

Viscosity, pH, and color values of skim milk and cream treated by ohmic heating and conventional heating. The viscosity, pH, and color values of skim milk and cream, treated and untreated, are shown in Table 2. The viscosity significantly decreased when skim milk was treated with both ohmic and conventional heating. pH values did not significantly differ among untreated, ohmic, and conventionally heated skim milk. L*, a*, and b* values were not significantly different between untreated skim milk and skim milk treated with ohmic heating. However, L* and a* values of conventionally treated skim milk were significantly different from untreated skim milk. In the case of cream, viscosity did not significantly differ between the untreated sample and the one that underwent ohmic heating. But the viscosity of cream increased with conventional heating. pH values did not significantly differ between untreated cream and cream that underwent ohmic heating. But pH values decreased significantly in cream subjected to conventional heating. L* and b* values did not significantly differ among cream samples that were untreated or that underwent conventional or ohmic heating. However a* values significantly decreased when cream was treated with both ohmic and conventional heating.

DISCUSSION

Novel thermal processing technologies such as microwave heating and infrared heating, and novel nonthermal processing technologies such as pulsed electric field and high pressure, can be used for milk processing. Ohmic heating is another one of the novel thermal processing technologies and is now receiving increased attention by the dairy industry. Ohmic heating is regarded as an alternative to indirect heating intervention for milk pasteurization, shell and plate heat exchangers that heat milk through direct contact with a hot surface *(5)*. Also APV International Ltd. (West Sussex, England) has developed commercial ohmic heating units for continuous sterilization of food products *(17)*.

Several studies have compared the inactivation effect of ohmic heating with that of conventional heating. The inactivation effect of ohmic and conventional heating on viable aerobes and *Streptococcus thermophiles* 2646 in milk was compared under identical temperature history conditions by Sun et al. *(19)*. They used an aluminum vessel for conventional heating. The inactivation effect of ohmic and conventional heating on *Bacillus subtilis* was compared under identical temperature history conditions by Cho et al.

TABLE 2. *Viscosity, pH, and color values of ohmic and conventionally treated skim milk and cream*[a]

	Treatment	Viscosity (cP)	pH	Color		
				L*	a*	b*
Skim milk	Untreated	2.43 ± 0.03 A	6.58 ± 0.02 A	53.57 ± 0.57 A	−2.29 ± 0.07 A	−1.19 ± 0.12 AB
	Ohmic	2.24 ± 0.02 B	6.59 ± 0.00 A	54.63 ± 0.64 A	−2.49 ± 0.12 A	−0.88 ± 0.02 A
	Conventional	2.21 ± 0.03 B	6.59 ± 0.00 A	59.22 ± 2.26 B	−3.05 ± 0.20 B	−1.57 ± 0.32 B
Cream	Untreated	41.33 ± 1.53 A	6.88 ± 0.02 A	72.24 ± 0.90 A	−2.18 ± 0.08 A	4.64 ± 0.08 A
	Ohmic	42.00 ± 1.00 A	6.86 ± 0.00 AB	73.26 ± 0.37 A	−2.37 ± 0.05 B	4.79 ± 0.07 A
	Conventional	45.33 ± 1.53 B	6.85 ± 0.00 B	73.30 ± 0.79 A	−2.35 ± 0.08 B	4.73 ± 0.14 A

[a] Values are expressed as mean ± standard deviation. Values in the same column for each sample that are followed by the same letter are not significantly different ($P > 0.05$). Color values are L* (lightness), a* (redness), and b* (yellowness).

(4). They used a Pyrex glass vessel for conventional heating. Comparing ohmic and conventional heating with identical temperature histories is a good way to confirm the nonthermal effect of ohmic heating. In our study, we compared ohmic and conventional heating with fixed temperature and time. Although some research demonstrates the nonthermal effect of ohmic heating, this phenomenon seemed to have only marginal effect on pasteurizing skim milk and cream. Previous studies also reported that the thermal effect is the primary parameter in the inactivation of microorganisms by ohmic heating *(10, 13)*.

Therefore, we confirmed how rapidly temperature can increase with ohmic heating versus conventional heating. The only difference between our ohmic and conventional heating chambers was the material used to construct them. Because an ohmic heating chamber should be made of an insulating material, we used polyvinyl chloride. For our conventional heating chamber we used very thin (2 mm) stainless steel to simulate current HTST pasteurization. For both skim milk and cream, temperature increased very rapidly using ohmic heating. The come-up time for ohmic heating was much shorter than for conventional heating. Moreover, because temperatures during ohmic heating were recorded at 0.6-s intervals, we could regulate temperature precisely. This is a more convenient and rapid way to control temperature than with conventional heating. Therefore, we demonstrated that ohmic heating is a more rapid and precise way to increase and maintain a constant temperature.

Three major foodborne pathogens were inactivated more effectively by ohmic heating than by conventional heating. Because temperature increases more rapidly with ohmic heating than with conventional heating, ohmic heating inactivates pathogens more rapidly. Among the three pathogens, *E. coli* O151: H7 was the most resistant in skim milk treated with conventional heating, followed by *L. monocytogenes* and *Salmonella* Typhimurium. The same trend was observed in skim milk that was subjected to ohmic heating. However, the difference in heat resistance among pathogens treated with ohmic heating was less than that observed during conventional heating.

Cream is usually made by heating whole milk to 50 to 55°C and skimming (<0.5% fat) in a separator. HTST pasteurization is in almost universal use in large creameries and is the most effective process for large daily production. A minimum process of 72°C for 15 s is stipulated, but higher temperatures may be used *(2)*. In our study, the temperature for cream was fixed at 82°C, which is 10.5°C higher than the temperature used for treating skim milk. Nonetheless, more time is required to pasteurize cream. The higher resistance of foodborne pathogens in cream is due to its high fat content. Juneja and Eblen *(8)* found that higher fat levels in beef resulted in increased heat resistance of *Salmonella* Typhimurium DT104. They concluded that higher fat content seems to confer a protective effect on bacterial cells suspended in fat due to the reduction in water activity. In contrast to skim milk, there were smaller differences in heat resistance in cream relative to pathogens when treated with conventional and ohmic heating.

During HTST pasteurization, skim milk is treated for 15 s after reaching the target temperature (71.5°C). Although treatment time (15 s) is very short, the come-up time is an important consideration. The longer the come-up time, the more skim milk quality is degraded. Because the come-up time for conventional heating is much longer than that of ohmic heating, viscosity and color values (L*, a*) changed when subjected to conventional heating. In contrast, only viscosity was changed when treated with ohmic heating. In the case of cream, viscosity, pH, and color value (a*) changed after treatment with conventional heating, whereas only color value (a*) changed after ohmic heating. Research has also shown that protein denaturation and chemical and flavor changes of milk were less with ohmic than with conventional heating *(6)*.

In our research study, we evaluated the feasibility of ohmic heating as an alternative technology to conventional dairy product pasteurization processing. Note the advantages of using ohmic heating to pasteurize skim milk and cream: (i) ohmic heating can increase temperature much more rapidly than conventional heating and (ii) quality parameters were degraded less by ohmic heating than by conventional heating. Because electrode corrosion is a factor that limits widespread application of ohmic heating *(9)*, further study will be needed to investigate electrode corrosion during ohmic heating used for dairy product pasteurization processing.

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