

High-Pressure Processing of Turkish White Cheese for Microbial Inactivation

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ABSTRACT

High-pressure processing (HPP) of Turkish white cheese and reduction of *Listeria monocytogenes*, total *Enterobacteriaceae*, total aerobic mesophilic bacteria, total molds and yeasts, total *Lactococcus* spp., and total *Lactobacillus* spp. were investigated. Cheese samples were produced from raw milk and pasteurized milk and were inoculated with *L. monocytogenes* after brining. Both inoculated (ca. 10^7 to 10^8 CFU/g) and noninoculated samples were subjected to HPP in a high-pressure food processor at 50 to 600 MPa for 5 and 10 min at 25°C. Reductions in *L. monocytogenes*, total aerobic mesophilic bacteria, *Lactococcus* spp., and *Lactobacillus* spp. in both pasteurized- and raw-milk cheese samples and reductions in total molds and yeasts and total *Enterobacteriaceae* counts in raw-milk cheese samples increased with increased pressure ($P \leq 0.05$). The maximum reduction of the *L. monocytogenes* count, ca. 4.9 log CFU/g, was obtained at 600 MPa. Because of the highly inhibitory effect of pasteurization, the total molds and yeasts and total *Enterobacteriaceae* counts for the cheese samples produced from pasteurized milk were below the detection limit both before and after HPP. There was no significant difference in inactivation of *L. monocytogenes*, total aerobic mesophilic bacteria, *Lactococcus* spp., and *Lactobacillus* spp. under the same treatment conditions for the raw milk and pasteurized milk cheeses and for 5- and 10-min treatment times ($P > 0.05$). No significant change was detected in pH or water activity of the samples before and after HPP. Our findings suggest that HPP can be used effectively to reduce the microbial load in Turkish white cheese.

Nonthermal food preservation technologies and especially high-pressure processing (HPP) have gained great importance for scientists, the food industry, and consumers due to positive effects on safety, quality, and sensory attributes of food products. Dairy, meat, seafood, poultry products, vegetables and vegetable products, fruit products, and acidified products have been processed successfully by HPP for microbial inactivation, and physical, chemical, and sensory characteristics have been unaffected (23).

Studies involving HPP include cheese making from HPP milk, acceleration of cheese ripening, and inactivation or reduction of pathogenic and/or spoilage microorganisms in cheese for increased safety and shelf life (24). Some HPP applications in different cheeses included reduction of variability of moisture content available within a block of cheese and generation of desirable cheese texture in reduced-fat Cheddar cheese (22), pasteurization of milk by HPP to increase cheese yield in semihard goat milk cheese and Cheddar cheese (8, 26), cheese ripening acceleration in Cheddar cheese (28), improvement of texture in low-fat semihard bovine milk cheese (16), inactivation of pathogenic and spoilage microorganisms by HPP in combination with other processes in Gouda, Kurpiowski, and Camembert cheeses (15), shelf life increase in fresh Cheddar and Mato cheeses (4, 17, 23, 25), and pressure shift freezing and

thawing of Cheddar and mozzarella cheeses (12). However, there is little information about HPP of Turkish white cheese.

Turkish white cheese is a brined (or pickled) cheese variety with a soft or semihard texture and a salty and acidic taste (11). Although Turkish white cheese has a soft texture when it is fresh, after ripening for 3 months in brine, it can be classified as semihard or semisoft (11). Turkish white cheese was originally produced from sheep or goat milk, but cow milk or a mixture of milks is now generally used for its production (11). According to data published in 2001, approximately 243,000 tons of Turkish white cheese are produced annually, representing 60 to 80% of the total cheese production in Turkey (1).

Turkish white cheese is usually made from raw milk in small dairies and from pasteurized milk in the large cheese factories. To obtain a better flavor profile, big dairies also can produce Turkish white cheese from raw milk. One of the most common defects in white cheese is undesired “eyes” or gas formation generally caused by coliform bacteria in the early stages of ripening. In raw milk cheeses, these bacteria may be natural contaminants of the milk, whereas in pasteurized milk cheeses contamination can occur during cheese production stages. Some other defects in white cheese, such as bitter taste, sticky surface, and mold formation, are caused by yeasts and molds. To prevent these defects, pasteurization of milk, application of good manu-

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facturing practices, and some other processes are required to provide safety and ensure the high microbial quality of Turkish white cheese.

Pathogen studies have revealed that *Listeria monocytogenes*, *Salmonella* Typhimurium, *Staphylococcus aureus*, and *Yersinia enterocolitica* can survive in Turkish white cheese, depending on salt concentration, ripening, starter culture activity, and storage time. *L. monocytogenes* is the most studied pathogenic microorganism in survival studies with Turkish white cheese (10) because this bacterium has been isolated from 13.4% of commercial Turkish white cheese (10). Therefore, one of the reasons to apply HPP to Turkish white cheese produced from raw milk was to determine whether HPP could be an alternative to pasteurization for inactivating the microorganisms that cause various cheese defects.

The objectives of the present work were to use HPP for Turkish white cheeses produced from raw milk (RM) and pasteurized milk (PM) and to determine the inactivation of *L. monocytogenes*, total lactic acid bacteria (*Lactococcus* spp. and *Lactobacillus* spp.), total *Enterobacteriaceae* (TE), total aerobic mesophilic bacteria (TAMB), and total molds and yeasts (TMY) under various pH and water activity conditions.

MATERIALS AND METHODS

Bacterial culture. *L. monocytogenes* (ATCC 19115) culture was obtained from Department of Microbiology (Ohio State University) on Trypticase soy agar (TSA; Becton Dickinson, Sparks, Md.) slants. The culture was transferred into Trypticase soy broth (Becton Dickinson) and incubated at $30 \pm 2^\circ\text{C}$ overnight before inoculation of the cheese samples at ca. 10^7 to 10^8 CFU/g for HPP.

Cheese production. Turkish white cheese production method was adapted from that of Uuncu (27). Cheese samples were produced from 35 liters of raw and pasteurized milk into two different vats on the same day. Full-fat milk was obtained from the Ohio State University Holstein herd on the day of cheese production. Full-fat milk was separated into skim milk and cream and then adjusted to a 1:1 protein:fat ratio.

For cheese made from pasteurized milk, raw milk was pasteurized at 63°C for 30 min and cooled to $31 \pm 1^\circ\text{C}$. Mesophilic starter culture (DVS-1, Chr. Hansen, Milwaukee, WI) containing *Lactococcus lactis*, *Lactobacillus cremoris*, and *Lactobacillus bulgaricus* was added at 0.02%. In addition to starter culture, CaCl_2 (20 g/100 liters) was added from a 40% solution. Double-strength fermentation-derived chymosin (CHY-MAX, Chr. Hansen) was added at pH 6.40 to 6.45, and coagulation was complete within 90 min. The coagulum was cut into 1- to 2-cm cubes. The curds were transferred to molds, covered with cheese cloth, and allowed to rest for 30 min without pressing. The curds were then pressed for 4 h at 15 kg for 35 liters and cut into 6- by 6- by 10-cm pieces. At the end of pressing, the pH of the cubes was 4.8 to 4.9. The cheese was at room temperature (ca. 22°C) during pressing.

For cheese produced from raw milk, milk was heated to $31 \pm 1^\circ\text{C}$ and no starter culture was added. The same procedure used for the cheese produced from pasteurized milk was followed, except the pH was different. The pH of raw curd from raw milk after pressing was around 5.9.

Cheese blocks from raw milk and pasteurized milk were

placed separately in a 15% brine solution containing 0.02% CaCl_2 at $22 \pm 1^\circ\text{C}$ for 3 h. The blocks were then packed into airtight and watertight plastic boxes filled with 14% brine and kept for 1 week before HPP to equilibrate the salt content in the cheese. Cheese samples were then prepared for HPP. Cheese production was carried out triplicates on different days.

Preparation of the samples. Four different sets of the cheese samples in triplicate were prepared. The samples were (i) cheese from raw milk, not inoculated, (ii) cheese from raw milk inoculated with *L. monocytogenes*, (iii) cheese from pasteurized milk, not inoculated, and (iv) cheese from pasteurized milk inoculated with *L. monocytogenes*. Twenty-five grams of the samples taken randomly from the 6- by 6- by 10-cm pieces, avoiding 1 cm of cheese surface, were weighed into sterile high-barrier film pouches (Wipak Wak 3.0 R, Winnipeg, Manitoba, Canada), and *L. monocytogenes* culture was added to inoculated samples. One milliliter of the culture was injected into the center of the cheese sample from each side with an automatic pipette, and the cheese samples were crumbled to create a homogenous cheese-*L. monocytogenes* culture mixture. After removal of air bubbles, the sterile pouches were heat sealed, placed in a high-barrier film bag (P640B film, Cryovac, Sealed Air Corp., Duncan, S.C.), and heat sealed. Two of these sample pouches were placed inside a larger high-barrier film bag and vacuum packed at -97 kPa with a MC-30 sealer (Sipromac, Inc., St. Germain Grantham, Quebec, Canada) before HPP. After vacuum packaging, all the samples were processed immediately by high pressure. Between sample preparation and HPP, the samples were kept refrigerated at ca. 7°C .

High-pressure treatment. A QFP-6 high-pressure food processor (Quintus, Flow Autoclave Systems, Inc., Columbus, Ohio) with a 2-liter pressure chamber was used for HPP. A digital data monitoring system attached to the HPP unit was used for collecting data. A K-type thermocouple mounted within the test area of the high-pressure processor monitored the temperature of the pressure-transmitting fluid. Another K-type thermocouple monitored the temperature of the water jacket surrounding the pressure vessel. The temperatures of the samples were adjusted before HPP, taking the heat of compression into account (19), so that $25 \pm 2^\circ\text{C}$ would be reached during HPP, and the cheese samples were subjected to HPP at 50 to 600 MPa for 5- and 10-min holding times. Control samples without pressure application were packaged the same way as HPP samples.

Measurement of physicochemical properties. The pH, water activity, moisture, and protein content of the samples were measured in the noninoculated samples. For pH measurement, 10 g of the sample was diluted 1:1 with deionized water and homogenized (Ultra-Turrax model T25, IKA Works, Inc., Wilmington, N.C.), and pH was measured with a Perpfect pH meter (Orion model 370, Fisher Scientific, Pittsburgh, Pa.). The moisture content of cheese samples was determined by a gravimetric method using a vacuum oven (3), and the protein content was determined by the Kjeldahl method (2). Water activity was measured with a water activity meter (AquaLab model CX2, Decagon, Pullman, Wash.).

Microbiological analyses. All samples in sterile pouches were analyzed for *L. monocytogenes*, total *Enterobacteriaceae* (TE), total aerobic mesophilic bacteria (TAMB), total molds and yeasts (TMY), total *Lactococcus* spp., and total *Lactobacillus* spp. before and immediately after HPP. The pouches were aseptically opened, and the samples were transferred into sterile stomacher bags. After dilution of the samples with 0.1% peptone water, the samples were stomached for 90 s, and corresponding dilutions

were surface plated onto TSA for *L. monocytogenes*, violet red bile agar (VRBA; Becton Dickinson) for TE, plate count agar (PCA; Becton Dickinson) for TAMB, and potato dextrose agar (PDA; Becton Dickinson) acidified with 10% tartaric acid for TMY and pour plated onto M17 agar (Becton Dickinson) for total *Lactococcus* spp. and deMan Rogosa Sharpe agar (MRS; Becton Dickinson) for total *Lactobacillus* spp. counts. TSA plates were incubated aerobically at $30 \pm 2^\circ\text{C}$ for 24 to 48 h, PDA plates were incubated aerobically at $22 \pm 2^\circ\text{C}$ for 5 to 7 days, VRBA plates were incubated aerobically at $30 \pm 2^\circ\text{C}$ for 24 to 48 h, and M17 and MRS plates were incubated anaerobically at $30 \pm 2^\circ\text{C}$ for 2 to 4 days. Results were calculated as log CFU per gram.

Data analyses. Minitab version 13.2 (Minitab, Inc., State College, Pa.) was used for data analyses. A two-tailed *t* test at the 95% confidence interval was conducted to determine differences in microbial inactivation and physicochemical properties before and after HPP. Tukey's multiple comparison test was performed to determine differences between cheese samples in different treatment groups.

RESULTS AND DISCUSSION

The pH, moisture, and protein content of the cheese samples made from raw milk were 5.7 ± 0.3 , $58.1\% \pm 2.2\%$, and $15.7\% \pm 1.2\%$. These values for the cheese samples made from pasteurized milk were 4.7 ± 0.04 , $55.1\% \pm 2.2\%$, and $16.1\% \pm 1.3\%$, respectively. There was no significant difference in moisture and protein content of the cheese samples between those made from raw milk and those made from pasteurized milk ($P > 0.05$); however, the pH values of these samples were significantly different ($P \leq 0.05$).

The pH of the samples made from either raw or pasteurized milk did not change significantly with increasing pressure ($P > 0.05$). At 600 MPa, the pH values of the cheese samples from pasteurized milk were recorded as 4.8 ± 0.03 and 4.9 ± 0.04 for 5- and 10-min treatment times, respectively. For the cheese samples from raw milk, the pH values of the samples at 600 MPa were 5.8 ± 0.62 and 6.1 ± 0.14 for 5- and 10-min treatments, respectively. There was no significant difference in the pH of the cheese samples made from pasteurized milk that was treated for 5 or 10 min ($P > 0.05$); similarly no significant difference was

observed between the cheese samples made from raw milk treated for 5 or 10 min ($P > 0.05$) (Table 1).

Evaluation of the water activity (a_w) of the samples indicated that pressure did not cause any significant change in the initial a_w of cheese samples. Control samples from pasteurized and raw milk had initial a_w values of 0.92 ± 0.00 and 0.96 ± 0.002 , respectively. Pressure applications of 50 to 600 MPa for 5 and 10 min changed the a_w values to 0.96 ± 0.002 and 0.96 ± 0.003 for the cheese samples from pasteurized milk and to 0.96 ± 0.002 and 0.96 ± 0.001 for the cheese samples from raw milk. The a_w of the samples did not significantly differ between the samples produced from raw milk and those from pasteurized milk, between those treated for 5 or 10 min, and between control and pressure-treated samples ($P > 0.05$) (Table 2).

The initial count of *L. monocytogenes* for control samples produced from pasteurized milk and raw milk were 7.5 ± 0.50 and 7.3 ± 0.49 log CFU/g, respectively. The first evident decrease in the numbers of *L. monocytogenes* was noted at 300 MPa, with a 3.1-log reduction for 5- and 10-min treatments (Fig. 1). At 600 MPa, reduction of *L. monocytogenes* increased to 4.4 and 4.9 log CFU/g for 5- and 10-min treatments, respectively, for the cheese samples made from pasteurized milk. Similarly, 5- and 10-min treatments caused 4.3- to 4.9-log reductions in the cheese samples made from raw milk. Reduction in the numbers of *L. monocytogenes* as a function of pressure application was significant ($P \leq 0.05$); however, inactivation was not affected by the use of raw or pasteurized milk and by the application of 5- or 10-min treatments ($P > 0.05$).

Microbiological analysis of Turkish white cheese made from pasteurized milk and processed for 5 min is presented in Figure 2. The initial levels of TAMB, *Lactococcus* spp., and *Lactobacillus* spp. were 7.9 ± 0.96 , 8.3 ± 0.61 , and 7.6 ± 0.65 log CFU/g, respectively. Cell counts after 600 MPa HPP were 3.2 ± 0.26 , 3.2 ± 0.23 , and 3.1 ± 0.41 log CFU/g, respectively. After a 10-min treatment, these initial numbers were reduced to 2.7 ± 0.26 , 2.8 ± 0.26 , and 2.9 ± 0.02 log CFU/g, respectively, for the cheese samples made from pasteurized milk. The number of survivors for TAMB, *Lactococcus* spp., and *Lactobacillus* spp.

TABLE 1. The pH values of Turkish white cheese samples treated by HPP

Pressure (MPa) at 25°C	Samples and processing times ^a			
	PM		RM	
	5 min	10 min	5 min	10 min
0.1	4.7 ± 0.04 A	4.7 ± 0.04 A	5.7 ± 0.34 B	5.7 ± 0.34 B
50	4.8 ± 0.08 A	4.9 ± 0.06 A	5.8 ± 0.58 B	6.1 ± 0.49 B
100	4.9 ± 0.06 A	4.9 ± 0.07 A	5.6 ± 0.46 B	5.9 ± 0.32 B
200	4.9 ± 0.13 A	4.9 ± 0.05 A	5.7 ± 0.56 B	6.2 ± 0.42 B
300	4.9 ± 0.05 A	4.9 ± 0.06 A	5.7 ± 0.52 B	6.2 ± 0.30 B
400	4.9 ± 0.06 A	4.9 ± 0.06 A	5.8 ± 0.53 B	6.1 ± 0.23 B
500	4.9 ± 0.03 A	4.9 ± 0.06 A	5.8 ± 0.66 B	6.2 ± 0.18 B
600	4.8 ± 0.03 A	4.9 ± 0.04 A	5.8 ± 0.62 B	6.1 ± 0.14 B

^a $n = 6$. Values are mean $\pm$ standard deviation. PM, cheese from pasteurized milk; RM, cheese from raw milk. Within each column and each row, means with different letters are significantly different ($P \leq 0.05$).

TABLE 2. Water activity values of Turkish white cheese samples treated by HPP

Pressure (MPa) at 25°C	Samples and processing times ^a			
	PM		RM	
	5 min	10 min	5 min	10 min
0.1	0.96 ± 0.003 A	0.96 ± 0.003 A	0.96 ± 0.002 A	0.96 ± 0.002 A
50	0.96 ± 0.003 A	0.96 ± 0.001 A	0.96 ± 0.003 A	0.96 ± 0.002 A
100	0.95 ± 0.002 A	0.96 ± 0.005 A	0.96 ± 0.003 A	0.96 ± 0.002 A
200	0.95 ± 0.004 A	0.96 ± 0.00 A	0.96 ± 0.002 A	0.96 ± 0.001 A
300	0.95 ± 0.003 A	0.96 ± 0.002 A	0.961 ± 0.00 A	0.96 ± 0.00 A
400	0.95 ± 0.005 A	0.96 ± 0.003 A	0.96 ± 0.005 A	0.96 ± 0.001 A
500	0.96 ± 0.001 A	0.96 ± 0.004 A	0.95 ± 0.002 A	0.96 ± 0.003 A
600	0.96 ± 0.002 A	0.96 ± 0.003 A	0.96 ± 0.002 A	0.96 ± 0.001 A

^a n = 6. Values are mean ± standard deviation. PM, cheese from pasteurized milk; RM, cheese from raw milk. Within each column and each row, means with different letters are significantly different ($P \leq 0.05$).

decreased with increased pressure and treatment time. Reduction in the initial number of TAMB, *Lactococcus* spp., and *Lactobacillus* spp. was significant ($P \leq 0.05$) (Fig. 3).

Pasteurization caused a large reduction in initial TE and TMY counts; TE and TMY counts for the control samples produced from pasteurized milk were below the detection limit before and after HPP. The lowest dilution (10^{-1}) from the spread plated samples yielded no colonies; therefore, these counts were reported as under the detection limit for the cheese samples made from pasteurized milk exposed to HPP for 5 and 10 min (Fig. 3).

Initial microbial counts for the cheese samples made from raw milk were 6.1 ± 0.30 , 7.6 ± 0.57 , 5.2 ± 1.44 , 7.8 ± 0.81 , and 7.2 ± 0.66 log CFU/g for TE, TAMB, TMY, *Lactococcus* spp., and *Lactobacillus* spp., respectively. For all the counts, the initial numbers decreased with an increase in the pressure from 50 to 600 MPa. After 5 min at 600 MPa, counts were reduced to 2.0 ± 0.00 , 3.6 ± 1.00 , 2.1 ± 0.23 , 3.1 ± 0.40 , and 3.3 ± 0.26 log CFU/g,

respectively (Fig. 4). After 10 min of treatment of the cheese samples from raw milk, the TE, TAMB, TMY, *Lactococcus* spp., and *Lactobacillus* spp. counts were reduced to 2.0 ± 0.00 , 3.3 ± 0.26 , 2.0 ± 0.00 , 3.1 ± 0.44 , and 3.1 ± 0.73 log CFU/g, respectively (Fig. 5). The reductions observed for all microbial counts for both 5- and 10-min treatments were significant ($P \leq 0.05$).

In general, 300 and 600 MPa resulted in 2- to 3-log and 4- to 5-log reductions, respectively, in *L. monocytogenes*, TAMB, and total lactic acid bacteria counts for the cheese samples from both raw and pasteurized milk and for TE and TMY counts for the cheese samples from raw milk. No significant difference was detected for inactivation of *L. monocytogenes*, TAMB, and lactic acid bacteria using

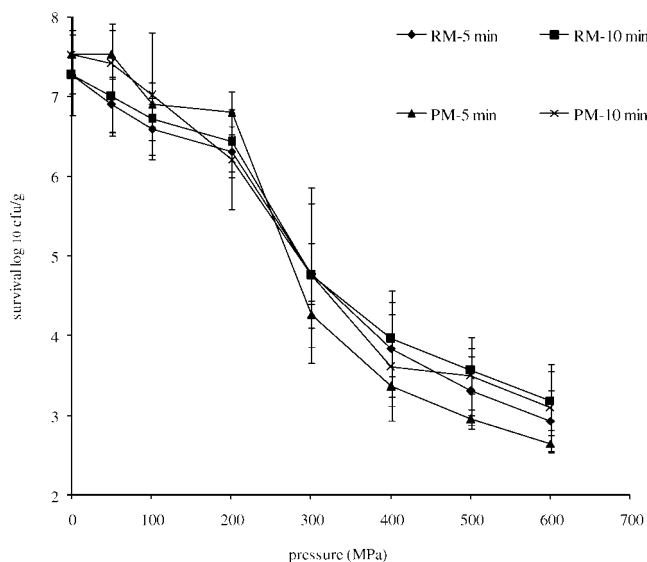


FIGURE 1. Reduction of *L. monocytogenes* counts in Turkish white cheeses made from raw milk (RM) and pasteurized milk (PM) and pressure treated for 5 and 10 min. Error bars represent the standard deviations, n = 9.

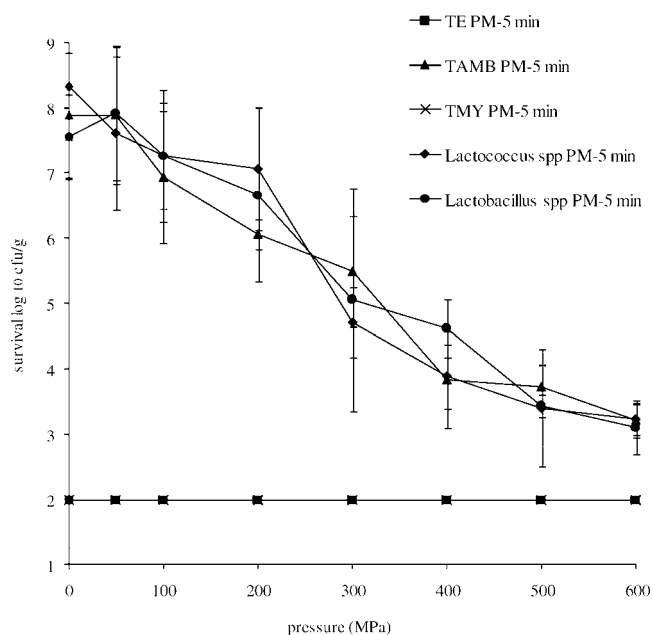


FIGURE 2. High-pressure processing of noninoculated Turkish white cheese made from pasteurized milk and treated for 5 min. TE, total Enterobacteriaceae; TAMB, total aerophilic mesophilic bacteria; TMY, total molds and yeasts; *Lactococcus*, total *Lactococcus* spp.; *Lactobacillus*, total *Lactobacillus* spp. TE and TMY counts were under the detection limit of 2 log CFU/g. Error bars represent the standard deviations, n = 9.

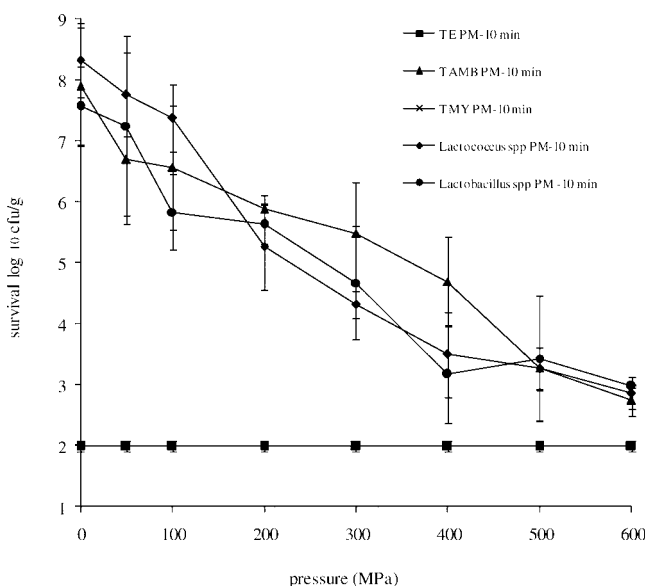


FIGURE 3. High-pressure processing of noninoculated Turkish white cheese made from pasteurized milk and treated for 10 min. TE, total Enterobacteriaceae; TAMB, total aerophilic mesophilic bacteria; TMY, total molds and yeasts; Lactococcus, total *Lactococcus* spp.; Lactobacillus, total *Lactobacillus* spp. TE and TMY counts were under the detection limit of 2 log CFU/g (ND). Error bars represent the standard deviations, $n = 9$.

the 5-min treatment time for the cheese samples made from pasteurized milk. Similarly, no significant difference in inactivation of *L. monocytogenes*, TAMB, and lactic acid bacteria was found for the 10-min treatment for cheese samples made from pasteurized milk (Figs. 2 and 3). Microbial inactivation in the cheese samples made from raw milk followed a similar pattern; no significant difference in inactivation of *L. monocytogenes*, TAMB, lactic acid bacteria, TMY, and TE was found for cheese samples made from raw milk processed for 5 min. For the cheese samples made from raw milk and treated for 10 min, no significant difference in inactivation of *L. monocytogenes*, TAMB, lactic acid bacteria, TMY, and TE was found ($P > 0.05$) (Figs. 4 and 5). Although inactivation at 10 min was greater than that at 5 min, the difference between the 5- and 10-min treatment groups was not significant ($P > 0.05$).

According to Szczawinski et al. (21), a 6-log reduction of *L. monocytogenes* occurred in ripened sliced cheese treated at 500 MPa for 15 min. Inactivation of *L. monocytogenes* in Gorgonzola cheese treated by pressures of 400 to 700 MPa for 1 to 15 min resulted in 99.999% reduction at 700 MPa for 15 min (5). Inactivation of *L. monocytogenes* in Turkish white cheese in the present study was similar to that for ripened, goat, and Gorgonzola cheese previously reported; however, inactivation of *L. monocytogenes* in cheeses manufactured from raw and pasteurized milk was lower than that previously reported. In a study conducted with French goat cheese manufactured from raw milk and inoculated with *L. monocytogenes*, lower pressures and shorter treatment times were sufficient to achieve a more than 5-log reduction. After 14 days of ripening for cheeses with a pH of 4.7, a reduction of more than 5.6 log

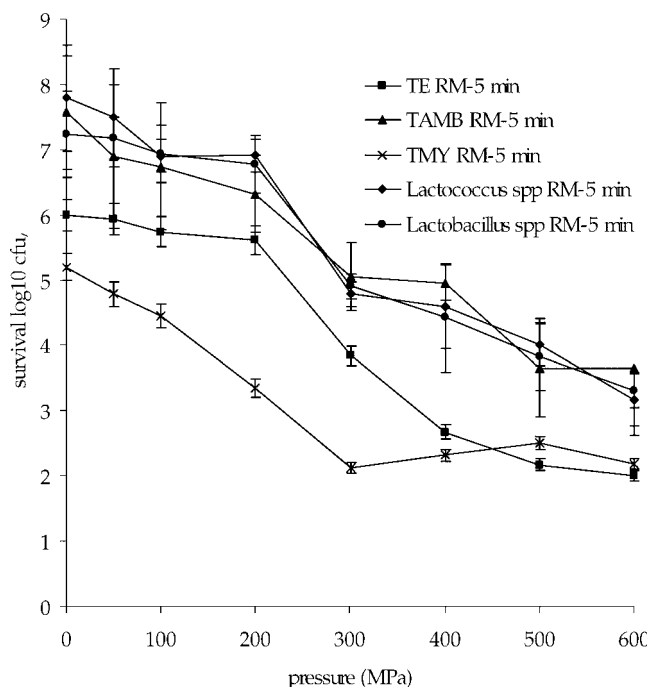


FIGURE 4. High-pressure processing of noninoculated Turkish white cheese made from raw milk and treated for 5 min. TE, total Enterobacteriaceae; TAMB, total aerophilic mesophilic bacteria; TMY, total molds and yeasts; Lactococcus, total *Lactococcus* spp.; Lactobacillus, total *Lactobacillus* spp. Error bars represent the standard deviations, $n = 9$.

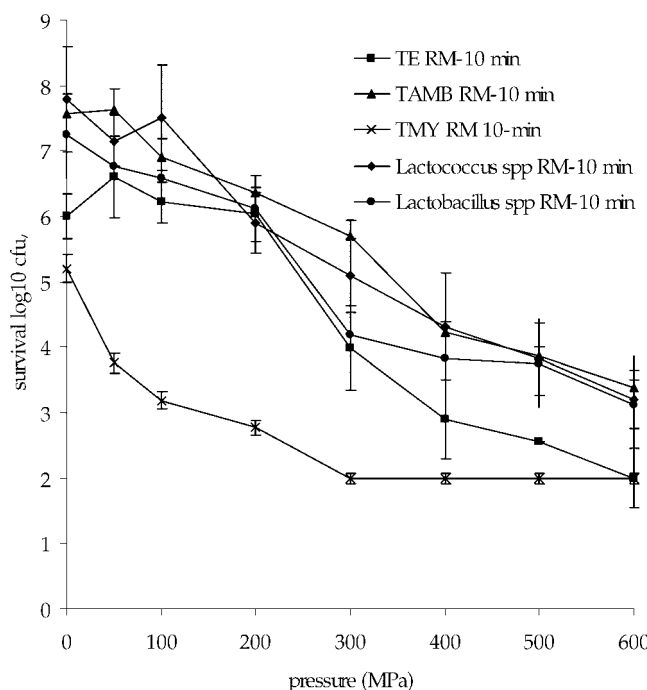


FIGURE 5. High-pressure processing of noninoculated Turkish white cheese made from raw milk and treated for 10 min. TE, total Enterobacteriaceae; TAMB, total aerophilic mesophilic bacteria; TMY, total molds and yeasts; Lactococcus, total *Lactococcus* spp.; Lactobacillus, total *Lactobacillus* spp. Error bars represent the standard deviations, $n = 9$.

was obtained by treatment at 400 MPa for 15 min, 450 MPa for 10 min, or 500 MPa for 5 min. The higher sensitivity of *L. monocytogenes* to HPP was attributed to the low pH and high a_w of the goat cheese (9). In the present study, similar conclusions could not be made based on the pH and a_w of the samples. The white cheese samples made from raw and pasteurized milk had very similar a_w values before and after HPP. The pH of the samples was significantly different between raw and pasteurized milk cheeses; however, this difference did not significantly affect the inactivation of *L. monocytogenes*. The inactivation obtained in both raw and pasteurized milk cheeses was not significantly different ($P > 0.05$).

The dominant microflora at the beginning of ripening in Turkish white cheese produced from raw milk was reported as *L. lactis* subsp. *lactis* and enterococci (*Enterobacter faecalis* and *Enterobacter faecium*). Other species of lactic acid bacteria, e.g., *Lactobacillus casei*, *Lactobacillus plantarum*, *Lactobacillus fermentum*, *Lactobacillus brevis*, *Leuconostoc lactis*, and *Leuconostoc mesenteroides* subsp. *dextranicum* also have been reported in Turkish white cheese (13). Mesophilic and/or thermophilic cultures are added to pasteurized milk as starters for the production of Turkish white cheese (7).

Inactivation of lactic acid bacteria by HPP has been studied in some types of cheeses but not Turkish white cheese. For example, inactivation of Cheddar cheese starter cultures of *Lactococcus* and *Lactobacillus* spp. by HPP was tested both in 0.1 M citrate buffer and in Cheddar cheese. A 6- to 8-log reduction was observed after HPP at 300 MPa in 0.1 M citrate buffer (pH 5.3) for all starters, and no viable cells remained after treatment at 400 MPa (18). Casal and Gómez (6) reported interstrain variation for *Lactococcus* and *Lactobacillus* in pressure-treated skim milk. The level of inactivation in these studies was similar to that found for the Turkish white cheese samples.

No data were available in the literature for reduction in total bacteria and total molds and yeasts in Turkish white cheese samples. However, in Gouda and Camembert cheeses, pressures above 400 MPa produced a significant reduction in the total microbial count (20). Application of 500 MPa at 25°C for 5 or 30 min increased the shelf life of refrigerated (4°C) vacuum-packaged fresh cheese treated with nisin at 7.1 mg/kg, and the initial microflora did not grow during 4 months of refrigerated storage (23). Kheadr et al. (14) reported that high-pressure treatment of milk favored the proliferation of certain groups of microorganisms, such as yeasts and heterolactic bacteria. Reps et al. (20) reported a significant decrease in total microbial counts at pressures >400 MPa and a 4- to 6-log reduction in the total microbial count at 800 MPa, depending on cheese type. Yeasts and molds were completely inactivated at 200 MPa in Gouda and Kurpiowski cheeses and at 400 MPa in 10-day-old Camembert cheese. The differences in degree of inactivation in these cheeses may be a result of the species and quantity of starter cultures and the acidity and composition of the cheese. A 2.85- to 3.27-log reduction of total aerobic bacteria was achieved in Gouda, Edamski, and Podlaski cheeses treated at 500 MPa for 15 min, depending on

the cheese type (21). Results for inactivation of total bacteria and total molds and yeasts in various cheeses (14, 20, 21, 23) were similar to those found in the present study.

According to previous studies the inactivation of *L. monocytogenes*, TE, TAMB, TMY, *Lactococcus* spp., and *Lactobacillus* spp. was different in different cheeses, depending on cheese composition and properties such as pH, water activity, salt content, ripening period, natural microflora of the cheese, and treatment conditions such as pressure, treatment time, and treatment temperature. Therefore, no exact comparison could be made with the previous studies performed with different cheeses under different processing conditions. Based on the cheese samples produced in the present study, the main difference was in the pH of the cheeses made from the raw and pasteurized milk. Although inactivation obtained in the pasteurized milk cheese was slightly higher than that in the cheese made from raw milk, the difference was not significant ($P > 0.05$). Another difference between the cheeses made from the two milk types was the level of background flora, TE and TMY. TE and TMY counts in the cheese made from pasteurized milk were much lower than those in the cheese made from raw milk. These differences could be associated with increased inactivation of *L. monocytogenes*, TAMB, *Lactococcus* spp., and *Lactobacillus* spp. in pasteurized milk. Inactivation of *L. monocytogenes*, TAMB, *Lactococcus* spp., and *Lactobacillus* spp. in pasteurized milk was slightly higher than that in the cheese made from raw milk; however, the difference was not significant ($P > 0.05$).

This study is the first regarding HPP and microbial inactivation in Turkish white cheese produced from both raw and pasteurized milk. HPP applied to Turkish white cheese can result in significant reduction of *L. monocytogenes*, TE, TMY, TAMB, *Lactococcus* spp., and *Lactobacillus* spp. without affecting the pH and water activity. HPP also can improve the safety of cheese made from raw milk or of pasteurized milk cheeses exposed to postpasteurization contamination. The microbial inactivation achieved in Turkish white cheese by HPP is very promising. However, further studies are needed to determine the effects of HPP on ripening and on the sensory and textural qualities of Turkish white cheese.

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