Eradicating *Listeria monocytogenes* from Fully Cooked Franks by Using an Integrated Pasteurization-Packaging System

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ABSTRACT

Surface pasteurization by applying steam or hot water before or after packaging of processed foods may be used to eliminate pathogens such as *Listeria monocytogenes* from ready-to-eat meat and poultry products. Surface pasteurization treatment with a mixture of pressurized steam and hot water was integrated into a continuous vacuum-packaging system to reduce *L. monocytogenes* from fully cooked franks. The franks (2.54 cm diameter by 15.24 cm length) were surface inoculated to contain up to 6 log CFU/cm² *L. monocytogenes*. The inoculated franks were treated at 121°C for 1.5 s in an arrangement of six franks per packaging chamber followed by immediate vacuum sealing of the top films of food packages in the same unit. A 3-log CFU/cm² reduction of *L. monocytogenes* on fully cooked franks was obtained using the integrated pasteurization-packaging system. The pasteurization depth was 1.27 mm below the surfaces of the franks. This process provides a commercially applicable means of ensuring food safety by effectively eradicating *L. monocytogenes* from ready-to-eat meat and poultry products at the very last possible step of food packaging before reaching retail consumers.

*Listeria monocytogenes* is a pathogenic bacterium found in soil, water, and vegetation and on the surface of equipment, floors, and walls and is often carried by healthy animals and humans (20). About 99% of listeriosis cases reported in the United States were transmitted by foods (21). *L. monocytogenes* is responsible for about 2,500 illnesses and 500 deaths in the United States each year (7). The case fatality of listeriosis is 20 to 30%, the second highest among bacterial diseases (7).

*L. monocytogenes* can spread by direct food contact with a contaminated surface, possesses a relatively high resistance to heat and salt, and is able to grow at refrigeration temperatures as low as 2°C or under low oxygen tension such as found in vacuum-packaged ready-to-eat (RTE) meat and poultry products (16, 20). Although the cooking processes currently applied by the U.S. meat and poultry industry generally meet the requirements of the U.S. Department of Agriculture Food Safety and Inspection Service (FSIS), the postprocess operations for RTE foods, such as peeling, sorting, loading, and slicing, are potential sources of pathogen recontamination of RTE meat and poultry products. An FSIS survey published in 2001 indicated that 1 to 10% of retail RTE meat and poultry products were contaminated with *L. monocytogenes* (6).

Recent incidences of foodborne outbreaks associated with *L. monocytogenes* prompted governmental regulatory agencies to impose a final rule on 6 October 2003 to control *L. monocytogenes* in RTE meat and poultry products (21). This rule requires that all establishments that produce RTE meat and poultry products that are exposed to the environment after lethality treatments will need to develop written programs, such as hazard analysis and critical control point systems, sanitation standard operating procedures, and other programs, to control *L. monocytogenes*.

Although sanitation regulations have helped to improve sanitary conditions in RTE meat and poultry processing plants, true aseptic conditions are virtually impossible to consistently achieve in commercial processing environments other than closed-system operations (1, 6, 19). Because *L. monocytogenes* cannot be completely eliminated from the food processing environment, the potential for *L. monocytogenes* recontamination of RTE meat and poultry products after processing and before retail packaging presents a food safety threat to public health. This threat has promoted processors to investigate ways to apply postprocess lethality treatments before or after packaging to eliminate *L. monocytogenes* from RTE meat and poultry products.

Studies have been conducted on post- and prepackage pasteurization methods using steam or hot water to reduce *Salmonella* or *Listeria* in RTE meat and poultry products (3, 5, 8–18). Compared with prepackage pasteurization methods, postpackage pasteurization methods may cause additional water purge (up to 20 g per package of franks) in meat packages due to the prolonged treatment required for heat to penetrate through the packaging materials. However, there is a potential for pathogen recontamination when using prepackage pasteurization methods from the reexposure of foods to the processing environment after the pasteurization treatment and before retail packaging.

Because of the large volumes of RTE meat and poultry products in markets and the diverse process operations in use commercially, the RTE food industry is in need of a practical postprocess lethality treatment method that is cost
effective and time efficient for eliminating pathogens without negatively affecting the quality of packaged foods. The practical and effective postprocess lethality treatment method should also disallow any chances of possible recontamination by pathogens that may be present in the processing environment before the foods are sealed in retail packages.

Based on the information obtained from conceptual studies using a prototype steam pasteurization machine for _Pediococcus acidilactici_, _Listeria innocua_, and _L. monocytogenes_, a continuous vacuum packaging system for RTE franks was retrofitted to integrate surface pasteurization by applying a mixture of steam and hot water at the normal operation speed of commercial packaging. This integration of surface pasteurization and vacuum packaging both minimizes the negative effects of heat on food quality by substantially reducing heat treatment time from minutes to seconds and reduces the likelihood of pathogen recontamination by immediately vacuum sealing the top films of food packages after heat treatment. The objective of this study was to validate the effectiveness of a continuous postprocess pasteurization-packaging system in reducing _L. monocytogenes_ in fully cooked franks at the very last possible step of food packaging before shipment for retail sale.

**MATERIALS AND METHODS**

**Product.** Fully cooked franks (2.54 cm diameter by 15.24 cm length) were obtained from a processor in retail packages containing six franks each. The franks contained about 56% moisture, 30% fat, 12% protein, and 0.9% sodium salt. The frank ingredients included beef, water, and less than 2% sodium lactate, salt, corn syrup, dextrose, sodium phosphate, sodium diacetate, sodium erythorbate (made from sugar), flavor, extracts of paprika, and sodium nitrite. The exact formulation of the franks was proprietary to the processor. The pH of the packaged franks was about 6.2, and they were kept at 4°C and used before the expiration dates on the labels.

**Culture preparation.** Five strains of _L. monocytogenes_ (ATCC 7644, 984, 19115, 51777, and 51414) were individually maintained by Deibel Laboratories (Madison, Wis.). To prepare each stock culture for test trials, a loopful of each _L. monocytogenes_ strain was transferred from tryptic soy agar plus 0.6% yeast extract (TSAYE) to 10 ml of tryptic soy broth plus 0.6% (TSBYE) and incubated at 35°C for 24 h as stock cultures. Aliquots (0.1 ml) of each stock culture were transferred to 9 ml of TSBYE and incubated at 35°C for 24 h as substock cultures. Bacteria in each substock culture were estimated at approximately 10⁶ CFU/ml.

**Surface inoculation.** Just before bacterial inoculation of fully cooked franks, the substock cultures were mixed in equal volumes to obtain a cocktail of _L. monocytogenes_ inoculation culture. Each retail package of franks was aseptically peeled open in a laminar flow hood, and each frank was placed in a sterile pan containing 300 ml of the _L. monocytogenes_ cocktail culture and slowly rotated lengthwise for 5 min to make sure that the culture covered the entire surface (including both ends) of the frank. After inoculation, the frank was removed from the inoculation culture, and the excess fluid was allowed to drip off. The inoculated franks were kept at 4°C for 45 to 60 min before being processed through the continuous pasteurization-packaging system.

At each test trial, inoculated and untreated franks that were prepared according to the same procedure as above were used as controls to calculate the initial inoculation concentration of _L. monocytogenes_ on the franks.

**Pasteurization-packaging treatment.** The inoculated franks were processed at 4°C through the continuous pasteurization-packaging system (RapidPak-SP210, Alkar-RapidPak, Lodi, Wis.) in an arrangement of six franks per packaging chamber in a double-chamber arrangement (eight chambers per index) along the packaging conveyor belt. The franks in each chamber were treated by a mixture of steam and hot water at 121°C for 1.5 s, immediately followed by vacuum sealing of the top films of the frank packages. After the process, the packages of franks were immediately placed in a cooler at 4°C to be analyzed for microbial survivors.

**Microbial enumeration.** All six franks in a packaging unit were microbiologically analyzed to determine the number of surviving _L. monocytogenes_ cells on the franks. Fifty milliliters of sterile phosphate buffer solution was used to rinse the surfaces of six franks placed in a plastic bag by shaking the bags for 2 min. Serial dilutions were poured onto TSAYE and overlaid with modified Oxford medium to resuscitate heat-injured cells (4). Colonies were counted after plates had been incubated at 35°C for 48 h. For detection of bacterial concentrations below the sensitivity of the plating method (10 CFU/cm²), an _L. monocytogenes_ enrichment procedure was used to qualitatively determine the presence of any survivors (4).

_L. innocua_ M1 was also evaluated in this study. This bacterial strain was developed as a heat-resistant indicator for _L. monocytogenes_ and was reported to be slightly more heat resistant than _L. monocytogenes_ (2). The procedures for culture preparation, inoculation, and enumeration for _L. innocua_ were similar to those for _L. monocytogenes_ and those described by Murphy and Berrang (10).

**Data analysis.** The initial and surviving _L. monocytogenes_ or _L. innocua_ after each pasteurization-packaging run were expressed as CFU per square centimeter of frank surface area. Ten (60 franks) to 20 (120 franks) packaging units were processed at each run of test trials. The mean log CFU per square centimeter from each run was calculated for _L. monocytogenes_ or _L. innocua_. The mean ± standard deviation of the replicated test trials was reported for surviving _L. monocytogenes_ or _L. innocua_ after pasteurization-packaging processes. The goal of this study was to validate the continuous pasteurization-packaging system as effective in reducing _L. monocytogenes_ in fully cooked franks.

**Water purge.** To determine the water purge in the packaged meat, after the meat packages were stored at 4°C for 24 h the juice in the meat packages was separated from the meat and weighed on a digital balance.

**RESULTS AND DISCUSSION**

Figure 1 shows the log CFU per square centimeter reductions of _L. monocytogenes_ in fully cooked franks that were processed through the continuous pasteurization-packaging system. At an initial inoculation concentration of 4.1 log CFU/cm², the mean _L. monocytogenes_ remaining on fully cooked franks passing through the pasteurization-packaging system was 0.79 log CFU/cm². This treatment achieved a 3.17- to 3.45-log reduction in _L. monocytogenes_ on the franks. In the conceptual study using a prototype pasteurization-packaging unit, at an inoculation concentration of about 2.5 to 3.5 log CFU/cm², no _L. monocytogenes_...
survivors were detected on any of 336 franks after enrichment.

In a previous study of postpackage pasteurization in which a reduction in *L. monocytogenes* was targeted (9), the changes in physical properties and sensory characteristics were evaluated for packaged RTE chicken strips (454 g per package) treated in ambient steam or hot water at 88°C for 34 min. Although there were no significant differences found for instrumental texture (shear force) and sensory attributes between treated RTE chicken strips and untreated controls, additional water purge was detected in the packaged chicken strips after exposure to ambient steam or hot water (9). Similar studies were also conducted for packaged franks. Water purge of up to 20 g per package of franks was obtained after postpackage pasteurization using steam or hot water.

In the present study, no physical differences were observed between the fully cooked franks processed through the continuous pasteurization-packaging system and the unprocessed franks sealed in original retail packages. The water purge from the franks processed through the same continuous pasteurization-packaging system was evaluated using uninoculated franks and was compared with that of unprocessed controls. The water purge in the final packages of the franks processed through the pasteurization-packaging system was about 2.4 to 3.6 ml, similar to the water purge obtained for the uninoculated franks and was compared with that of unprocessed controls. The water purge obtained for the uninoculated franks during pasteurization-packaging processes were simulated using a computer program (FPSolver PLT version 1.0, FPS Technologies LLC, Fayetteville, Ark.).

The effectiveness of the continuous pasteurization-packaging system on reducing *L. monocytogenes* from fully cooked franks was also evaluated at different initial inoculation concentrations of the pathogen. At a concentration of 6.3 log CFU/cm², 3-log reductions were obtained for *L. monocytogenes* on fully cooked franks after the pasteurization-packaging process (Fig. 2). Thus, use of this system as a postprocess lethality treatment method resulted in a 3-log CFU/cm² reduction in *L. monocytogenes* on fully cooked franks, and these numbers were not affected by initial inoculation concentrations of *L. monocytogenes*.

Because *L. innocua* has been used as a heat-resistant indicator for *L. monocytogenes* and was reported to be slightly more heat resistant than *L. monocytogenes* (2), in this study, the reduction of *L. innocua* on fully cooked franks was evaluated following the same procedures for culture inoculation and pasteurization-packaging as were followed for testing *L. monocytogenes* using the same continuous pasteurization-packaging system. At an inoculation concentration of 4.4 log CFU/cm², 3.1- to 3.9-log reductions were obtained for *L. innocua* from the franks processed through the pasteurization-packaging system (Fig. 3), verifying that this system was effective in controlling the most heat-resistant *Listeria* on fully cooked franks.

Because there are folds at the ends of RTE franks but not in the middle, the ends of the franks were evaluated separately from the middle cylindrical sections using *L. innocua* and *L. monocytogenes*, respectively. For the same franks that were processed through the pasteurization-packaging system, no significant differences (at *α* = 0.05) in the survival of *L. innocua* or *L. monocytogenes* were found between the ends and the middle sections of the franks (data not shown).

The temperature changes at different depths of the franks during pasteurization-packaging processes were simulated using a computer program (FPSolver PLT version 1.0, FPS Technologies LLC, Fayetteville, Ark.). Figure 4 shows the meat temperatures at different depths of the franks from the surface toward the center of the frank after treatment at 121°C for 1.5 s. After pasteurization in a mixture of steam and hot water at a temperature of 121°C for 1.5 s, the heat penetration depth was simulated at 0.127 cm below the frank surface. The changes in meat temperature were measured experimentally using thermal probes placed at different locations on or in the franks. The temperature measurements on the frank surface and in the frank center were consistent with the results from simulations. However, because of the short heat treatment time (1.5 s), the precise
depth of heat penetration in the franks could not be easily physically measured with thermal probes.

In previous studies of postpackage pasteurization methods involving steam at 85 to 95°C for 4 to 8 min, Gill et al. (3) achieved 4- to 5-log reductions in *L. monocytogenes* on RTE meat and poultry products, including beef salami and turkey kielbasa. Muriana et al. (8) found that *L. monocytogenes* inoculated on RTE turkey, beef, and ham were reduced 2 to 4 log after postpackage heat treatment in a water bath at 90 to 96°C for 2 to 10 min. Using a prototype flash pasteurization machine, Kozempel et al. (5) conducted surface pasteurization studies at a steam temperature of 138°C by alternately applying multiple cycles of steam and vacuum on franks and obtained 3- to 5-log reductions for *L. innocua* in less than 3 s.

The continuous pasteurization-packaging system used in this study was designed to provide pressurized steam and hot water (121°C) in a precisely controlled packaging chamber and therefore was able to significantly reduce pasteurization time to 1.5 s. Each commercial pasteurization-packaging system will be retrofitted specifically for each type of RTE meat or poultry product to optimize the pasteurization-packaging process within the normal commercial packaging line speed. The systems will be validated to achieve the required *L. monocytogenes* reductions, to minimize water purge, and to maintain food stability. After pasteurization, the top films of food packages will be immediately vacuum sealed to minimize the reexposure time of the treated foods to the processing environment.

The commercial packaging room of an RTE meat or poultry processing facility normally is temperature controlled at 40°F (4.4°C). If franks were pasteurized at 121°C for 1.5 s and then naturally cooled at 4.4°C, it would take about 34 s for the heat-treated franks to cool close to 4.4°C (Fig. 5). Besides the functions of a precisely controlled pasteurization and vacuum-packaging machine, the integrated pasteurization-packaging system also provides immediate cooling of the foods on the system conveyor to allow the packaged foods to be at the specified temperature (e.g., 4.4°C) by the time the packaged foods exit the system.

The integration of steam and hot water pasteurization with vacuum packaging allows food products to be vacuum sealed immediately following the postprocess lethality treatment, therefore eliminating the risk of any further pathogen recontamination during the packaging operation. Compared with postpackaging pasteurization, integrated pasteurization-packaging systems would also be more economical for RTE food producers because of the substantial reduction in operational cost.

Postpackaging pasteurization requires that meat or poultry products be packaged in a thick (0.2 to 0.28 mm) packaging film to withstand a longer period of harsh heat treatment required to eliminate pathogens, resulting in an increase of operational cost by about 50% as compared with the use of thinner packaging films (0.08 to 0.15 mm). Thicker packaging films are more costly and prolong the time for pasteurization treatment by creating a barrier to heat transfer. Increasing packaging film thickness slowed heat penetration through the packaging material and subsequently reduced the thermal inactivation rate of pathogens in packaged meat and poultry products (17).

Because heat treatment is applied just before the final step of vacuum sealing food packages, the integration of pasteurization into a vacuum-packaging system allows the RTE food processors to use thinner retail packaging films (0.08 to 0.15 mm) and to eliminate the water purge problems relating to prolonged heat treatment associated with postpackaging pasteurization of RTE meat or poultry products.

A continuous pasteurization-packaging system was used to reduce *L. monocytogenes* concentrations on fully cooked franks. A 3-log reduction in *L. monocytogenes* was achieved for packaged RTE franks after 1.5 s of pasteurization treatment. The results from this study provide information useful to the RTE meat and poultry processors in choosing alternatives for postprocess lethality treatments to eliminate pathogens from RTE foods.

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**FIGURE 4.** Temperature changes at different depths between the surface and the center of fully cooked franks at a steam–hot water temperature of 121°C for 1.5 s.

**FIGURE 5.** Temperature profile for the surfaces of fully cooked franks pasteurized at 121°C for 1.5 s and cooled at 4.4°C.


