Prepackage Surface Pasteurization of Ready-to-Eat Meats with a Radiant Heat Oven for Reduction of *Listeria monocytogenes*

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MS 02-427: Received 26 November 2002/Accepted 26 March 2003

ABSTRACT

In this paper, a thermal process for the surface pasteurization of ready-to-eat (RTE) meat products for the reduction of *Listeria monocytogenes* on such products (turkey bologna, roast beef, corned beef, and ham) is described. The process involves the passage of products through a “tunnel” of heated coils on a stainless steel conveyor belt at various treatment times relevant to the manufacture of processed meat for the surface pasteurization of RTE meat products. Two inoculation procedures, dip and contact inoculation, were examined with the use of a four-strain cocktail of *L. monocytogenes* prior to heat processing. With the use of radiant heat prepackage surface pasteurization, 1.25 to 3.5-log reductions of *L. monocytogenes* were achieved with treatment times of 60 to 120 s and air temperatures of 475 to 750°F (246 to 399°C) for these various RTE meats. Reduction levels differed depending on the type of inoculation method used, the type of product used, the treatment temperature, and the treatment time. Prepackage pasteurization (60 s) was also combined with postpackage submerged water pasteurization for formed ham (60 or 90 s), turkey bologna (45 or 60 s), and roast beef (60 or 90 s), resulting in reductions of 3.2 to 3.9, 2.7 to 4.3, and 2.0 to 3.75 log cycles, respectively. These findings demonstrate that prepackage pasteurization, either alone or in combination with postpackage pasteurization, is an effective tool for controlling *L. monocytogenes* surface contamination that may result from in-house handling.

*Listeria monocytogenes* is a significant foodborne pathogen that is capable of causing foodborne illnesses that may simulate flulike conditions (i.e., listeriosis). Serious infections can further lead to abortions in pregnant women and meningitis. Mortality rates can reach 25 to 30% overall in large outbreaks and may even be as high as 50% (septi- cemia) to 70% (meningitis) for primary infected individuals or >80% for perinatal-neonatal infections. Consequently, both the U.S. Department of Agriculture’s Food Safety and Inspection Service (USDA-FSIS) and the U.S. Food and Drug Administration (FDA) have issued a zero tolerance for this pathogen in ready-to-eat (RTE) foods, declaring it an “adulterant” and “added agent” harmful or injurious to consumers (15).

*L. monocytogenes* is widespread in the environment and has been found in plants, soil, animals, water, silage, and other processing environment sources. The organism is heat and salt tolerant, can form biofilms on food processing equipment (16), and has the ability to grow at refrigeration temperatures. Like many animal-associated pathogens, *L. monocytogenes* can gain entry into meat processing facilities through contaminated carcasses and/or boxed beef, poultry, or other meats (14). Epidemiological studies indicate that *L. monocytogenes* is often transferred through cross-contamination from employees, drains, standing water, residues, floors, and food contact surfaces, suggesting that a finished RTE product can readily acquire *L. monocytogenes* contamination prior to final packaging while the product is exposed to environmental contamination (9, 12). Thus, sanitation programs are critical in controlling the pathogen in processing environments.

Foods typically associated with listeriosis are foods that are highly processed and have an extended shelf life, foods such as RTE processed meats (6). *L. monocytogenes* can be found in the environments of food processing facilities, and therefore its elimination from these types of facilities is of particular concern to manufacturers of RTE meats. Alarming, the results of USDA-FSIS RTE meat sampling program from 1998 to 2001 showed *L. monocytogenes* incidence rates of 5.7% for sliced luncheon meats, 4.4% for small-diameter sausages (hot dogs), and 3.1% for cooked roast beef. Since being labeled as an adulterant of RTE foods, *L. monocytogenes* has been involved in numerous product recalls, foodborne illnesses, and even deaths due to the consumption of contaminated RTE meat products (1–3). One of the largest outbreaks arising from postprocessing contamination of RTE meats, occurring in 1998, involved a large manufacturer of hot dogs and luncheon meats and resulted in 21 deaths and >100 illnesses in 14 states, leading to the recall of 35,000,000 lb of hot dogs and deli meats (1, 2).

Postprocessing contamination of RTE meats with *L. monocytogenes* has become a major concern to the value-added processed-meat industry, and surface pasteurization is becoming an effective means for reducing the risk posed by such products. Much of the research on meat surface pasteurization has been related to steam pasteurization (i.e.,

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Frigoscandia, Inc., a manufacturer of equipment for surface pasteurization using steam) of exposed raw beef carcass surfaces to reduce the incidence of Escherichia coli O157: H7 that might end up in trimmings and ground beef (4). The Listeria problems currently encountered in the RTE processed meat industry are the result of a combination of (i) Listeria contamination from the processing environment and from workers and (ii) a high degree of postprocessing product exposure to potential contamination sources and handling practices that could allow incidental surface contamination (worker handling, removal of deli products from cook-in bags, exposed product on trays or carts wheeled into smokehouses, etc.). Various technologies and approaches to help reduce the risk of postprocessing contamination have emerged, including chemical-antimicrobial treatments (5, 11, 13), irradiation (not yet approved for RTE meats) (16), and thermal processes such as postpackage submerged water pasteurization (7, 8). These techniques can be used either individually or in combination to produce a “hurdle” effect on pathogen contaminants. To provide a solution to this problem, we have been studying surface pasteurization as a convenient and effective means of reducing incidental contamination on product surfaces immediately before (prepackage) or after (postpackage) final packaging. Postpackage pasteurization (7) has already been implemented by several large meat processors. The objective of this work was to investigate the effectiveness of a radiant heat oven for the prepackage surface pasteurization of RTE deli meats as a means of controlling L. monocytogenes on fully cooked meat products (turkey bologna, deli ham, corned beef, and roast beef).

MATERIALS AND METHODS

**Bacterial strains.** A mixture of four strains of L. monocytogenes (Scott A-2, serotype 4b; V7-2, serotype 1/2a; 39-2, retail hotdog isolate; 383-2, ground beef isolate) was used for the inoculation trials. These strains were made resistant to streptomycin (100 μg/ml; Sigma Chemical Co., St. Louis, Mo.) and rifampycin SV (10 μg/ml; Sigma) and were plated on general-purpose agar (tryptic soy agar [TSA]; Difco, Becton-Dickinson, Franklin Lakes, N.J.) containing these antibiotics when they were selectively plated for the inoculum cultures. This approach allows the recovery of viable and heat-injured cells without the need for harsh selective media that may prevent the growth of heat-injured cells (e.g., modified Oxford agar) or in lieu of indigenous contaminating bacteria. For the culturing of the bacterial strains, 100 μl of thawed frozen culture was transferred to 10 ml of brain heart infusion (BHI) broth and incubated overnight at 30°C; each of the four cultures was then transferred individually to 40 ml of BHI culture and later combined (for a total volume of 160 ml) prior to their use in the dip inoculation treatment. For surface contact inoculation, overnight cultures were mixed in equal proportions, and the mixture (100 μl) was surface plated onto tryptic soy agar (TSA) that was held overnight at 30°C.

**Product inoculation.** Samples of roast beef (whole and split rounds), corned beef (whole logs), and ham (formed and whole muscle) generally weighed 4 to 13 lb (1.8 to 5.9 kg), and turkey bologna samples were composed of ~2-lb sections. Except for two lots of roast beef (received frozen and allowed to thaw), all products were received fresh and refrigerated from commercial processors as they would normally be shipped for sale to retailers without the additional thermal processing. The products were stored at 3°C (37.4°F) upon receipt and were removed from refrigerated storage just prior to inoculation, so the internal temperature was the same. Immediately before they were used, products were taken from refrigerated storage, removed from their packaging wrap, and inoculated with L. monocytogenes by the dip inoculation method or by a contact inoculation method. Control samples were also inoculated for each replication trial but were not heated; these samples were used to determine the basal recovery level for the inoculated microorganisms.

For the dip inoculation method, ca. 160 ml of a four-strain mixture (i.e., 4 × 40 ml) of L. monocytogenes was placed in a stainless steel bowl into which individual product pieces were dipped and rotated until all exposed surfaces had been wetted with the mixed culture. Product pieces were then placed on a sterile tray for 5 min to allow excess culture to drain off and were then placed on a conveyor belt leading into the radiant heat oven. With the use of the dip inoculation method, inoculation levels of ca. 1 × 10⁶ to 3 × 10⁶ CFU per product were typically achieved, as determined by recovery from inoculated but unheated control samples.

For the contact inoculation method, sponge-foam padding material (ca. 5 to 6 cm thick) was cut to the shape of a petri plate, autoclaved in foil-covered beakers, and used to pick up the mixed-strain inoculum lawn from inoculated petri plates after overnight incubation on agar plates with the use of a contact and twist motion. The inoculum was then contact inoculated onto the surface of the product with the same twist motion. The inoculated product was then placed on the conveyor leading into the radiant heat oven. As determined from nonheated control samples, the contact inoculation method also provided initial L. monocytogenes levels of 1 × 10⁶ to 3 × 10⁶ CFU per product sample.

**Prepackage pasteurization with a radiant heat oven.** A radiant heat oven (480 V, 30 A; Infrared Grill) was obtained from Unitherm Foodsystems (Bristow, Okla.) and installed in our pathogen processing pilot plant (Fig. 1A and 1B). The oven consisted of a stainless steel conveyor belt with heating elements positioned above and below it (Fig. 1). Heating coils had 12 in. (30.5 cm) of lateral clearance at the level of the conveyor belt and 8 in. (20.3 cm) of vertical clearance above the belt; separate bottom coils were positioned 5 in. (12.7 cm) below the belt. The coils themselves were spaced 2.5 to 3 in. (6.3 to 7.6 cm) apart. Inoculated product pieces were passed through the radiant heat oven (Fig. 1) for various treatment times at full power (no. 5 dial setting for ham and roast beef) or 80% power (no. 4 dial setting for turkey bologna). Products were processed for treatment times of 45 to 120 s depending on the resilience of the product and the throughput requirements of the product’s processors; treatment times were adjusted by altering the speed of the belt. Product logs were placed lengthwise on the belt. Half rounds of roast beef were pasteurized both with the cut face facing the end of the oven and with the cut face facing to one side. After passage through the oven, product samples were placed into a sterile bag, chilled in an ice-water slurry, and rinsed with a chilled sterile diluent (50 ml of 0.1% buffered peptone water) to recover cells for microbial analysis (usually within 15 to 20 min); inoculated but unheated control samples were treated similarly. The same procedure was used for all meat samples.

**Postpackage surface pasteurization.** Postpackage surface pasteurization of fully cooked deli ham, roast beef, and turkey bologna was carried out as described previously with a 50-gal (189-liter) steam-injected temperature-controlled water bath (7).
For samples processed by postpackage pasteurization alone (roast beef), we used a 25-ml inoculum. Additional resuspension diluent was used after pasteurization to ensure the recovery of the remaining inoculum.

**Combination pre- and postpackage surface pasteurization.** We investigated a combination pasteurization process that included a short prepackage pasteurization treatment (for 45 or 60 s) followed quickly by vacuum packaging and postpackage pasteurization (for 45, 60, or 90 s) by submersion and subsequent microbial analysis as described previously (7).

**Product temperature measurement.** Product temperatures were measured by several methods. Temperature-hardened DataTrace probes (Mesa Labs, Lakewood, Colo.) were placed at the tops, bottoms (offset to one side), sides, fronts, and backs of turkey bologna samples to determine the oven’s temperature distribution on all sides of the product, which could not easily be determined by any other method (Fig. 1C). An infrared digital thermometer (Raynger Model ST80, Raytek, Santa Cruz, Calif.) that could provide the average, minimum, and maximum temperatures of the locations of eight infrared dots projected onto a product in a circular pattern was also used (Fig. 1D).

**Microbiological analysis.** For the recovery of the inoculum bacteria remaining after radiant heat and/or postpackage pasteurization, products were placed into large sterile bags, and 25 to 50 ml of buffered peptone water was added. The bags were then shaken and massaged for 5 min to resuspend surviving bacteria in the rinse buffer. Recovery of the rinse buffer was followed by appropriate serial dilutions and pour plating on TSA containing the antibiotics specified above. The plates were then incubated for 48 h at 30°C.

**Experimental design.** Except for one trial involving frozen-and-thawed roast beef that was carried out in duplicate, all trials were carried out in triplicate. Inoculated control samples and experimental samples were run in pairs for each processing condition within a replicate. Different replications were carried out on separate days with different lots of the same product and with pairs of samples from the same lot for each test condition. Standard deviations were obtained for multiple samples in the various replications. Treatment times were limited to those of practical application by the various participating processors.

**RESULTS AND DISCUSSION**

In this study, we examined prepackage surface pasteurization of RTE meats with the use of a radiant heat oven (Fig. 1A and 1B) alone and in combination with postpackage pasteurization (7) for the reduction of incidental *L. monocytogenes* contamination that could occur during postprocessing handling and packaging.

We examined the surface temperatures of a turkey bologna product with temperature-hardened probes. With the use of paired placements of probes (Fig. 1C) on turkey bologna (top-offset-bottom, left side–right side, front face–rear face) we were able to examine the temperatures on the various surfaces in order to test for major discrepancies. The largest discrepancy observed was that between the upper and lower product surface temperatures (Fig. 2A), which was a result of the “shielding” of the bottom of the product by the stainless steel mesh conveyor belt and was alleviated (Fig. 2B) by a design modification. In order to alleviate this condition, the manufacturer suggested making...
a rotational adjustment to the heating coils underlying the conveyor belt (Fig. 2C) to move the coils closer to the belt and the overlying product’s bottom surface (Fig. 2D). This modification resulted in a noticeable and significant improvement in the top and bottom heating profiles compared with what had previously been observed. It should be noted that the “bottom” probes were placed “off center” and were not influenced by the temperature of the belt, which is nominally 95 to 99°F (35 to 37°C) upon its return to the oven entrance, since approximately 65 to 70% of the circuit of the circular belt is outside the oven; this is also the case for larger commercial systems.

Although we used metal-tipped probes to obtain surface measurements, we recognized that these probes could be susceptible to errors. If the probes are placed 1 to 2 mm too deep (along the surface), they may measure more surface temperature, and if placed too high, they may be influenced more by air temperature, and therefore extreme care was taken in their placement. Our intention was to determine whether gross temperature differences existed, because we expected that different products of different shapes and sizes would be positioned closer to or farther from the upper heating coils in practical use, and this would present a problem with any fixed-distance radiant oven. A handheld infrared thermometer that gave the average temperatures at the locations of eight infrared dots projected onto the surface of a product (Fig. 1D) was also used. At first, this infrared thermometer appeared to be a better means of obtaining accurate surface temperature measurements. However, temperature values would change as either conveyor belt or hand movement would change the positions of the dots and the exact points that were being mea-
measured. It is conceivable that a mounted infrared temperature sensor-monitor could provide continuous monitoring of product as it exits the oven to provide a continuous real-time alert if targeted surface temperatures are not achieved (i.e., with the sensor-monitor pointing at the product, perhaps through a hole in the exit housing, as it exits the oven). With the handheld infrared monitor, we observed surface temperatures for ham in the ranges of 138 to 162°F (59 to 72°C; 30-s treatment time), 147 to 189°F (64 to 87°C; 45-s treatment time), 154 to 209°F (68 to 98°C; 60-s treatment time), and 165 to 215°F (74 to 102°C; 75-s treatment time). Some cut meat products (turkey bologna, roast beef half rounds) showed somewhat lower temperatures than other surfaces, either because the cut flat side was offset from directly facing the heat source or because the cut sides also showed slight sweating (purge) during heating. Occasionally, surface temperatures as high as 250°F (121°C) would be observed, but temperatures would quickly decrease as the product moved.

As with postpackage pasteurization, care should be taken in developing microbial-reduction processing models based on surface temperatures without confirmatory inoculation studies. It is clear from various high surface temperature measurements we obtained that the accompanying microbial reduction was not in line with what would be expected on the basis of extrapolation from D-values (decimal reduction times) for the inoculated pathogens (7). Unlike the heating of fully cooked products to a specific internal temperature so that the entire product from the center outward has reached at least the target temperature, brief surface heating may not necessarily penetrate all of the cuts, folds, and crevices that can be accessed by bacteria, and therefore single-point, or even multipoint, temperature readings for the outermost surface may be of limited practical application.

In previous studies of postpackage pasteurization, a fixed amount of inoculum was added to each of the products in vacuum-packaging bags before the bags were vacuum sealed (7). This method of inoculation had to be modified for use with surface inoculation of a nonpackaged product, and therefore we examined both a dip inoculation method and a contact inoculation method and contemplated the practical difference between the two methods after they had been used in several pasteurization trials. RTE deli ham and roast beef half rounds inoculated by both methods were surface pasteurized (Fig. 3). The results obtained indicate that L. monocytogenes reductions for the contact inoculation method were 1 to 2 log cycles larger than those for the extreme dip inoculation method. During the radiant heat surface pasteurization of hams inoculated with L. monocytogenes and processed for 45 to 75 s, we obtained 0.75- to 1.85-log reductions when the dip method was used and 2.7- to 3.9-log reductions when the contact inoculation method was used (Fig. 3A). Similarly, with roast beef we achieved 1.5- to 2.2-log reductions for the dip inoculation method and 2.5- to 3.8-log reductions for the contact inoculation method when samples were processed for 60 to 90 s (Fig. 3B). The differences between the two inoculation methods are reasonably assumed to be due to the aggressive infiltration of small cracks, crevices, and folds, which protects some of the bacteria from the full heating regimen, when the dip method is used.

Our results indicate that radiant heat pasteurization can reduce incidental contamination that may be acquired upstream during postprocessing handling. We propose that this process would be most effective just prior to final packaging, a stage for which no such microbial interventions currently exist. However, there could still be concerns about contamination during the final packaging, although such contamination would be minimized if the product were

![FIGURE 3. Radiant heat surface pasteurization of (A) ham and (B) roast beef inoculated by the dip method or the contact method and processed at highest power setting for the time indicated. Each data point represents the mean for paired samples from triplicate replications. Error bars represent standard deviations of the mean.](image-url)
packaged immediately while still hot. With this in mind, we further examined a combined pre- and postpackage pasteurization step that would provide the benefit of direct surface heating of prepackage pasteurization along with the added benefit of further pasteurization after the final packaging while the surface is still warm (at which point no further exposure to contamination due to handling would occur). For formed ham and turkey bologna, we obtained 1.35- and 1.53-log reductions of L. monocytogenes, respectively, when a 60-s radiant heat surface pasteurization step was used with product inoculated by dip method, our most aggressive inoculation method (Fig. 4). When prepackage pasteurization of the ham was followed by 60- or 90-s postpackage pasteurization at 200°F (93.3°C), we obtained overall 3.17- and 3.91-log reductions of L. monocytogenes, respectively (Fig. 4A). When prepackage pasteurization of the turkey bologna was followed by 45- or 60-s submersed water postpackage pasteurization, we obtained overall 2.73- and 4.3-log reductions of L. monocytogenes, respectively (Fig. 4B).

The results of our examination of both the dip and the contact inoculation methods suggest that the contact inoculation method is more typical of the manner in which incidental contamination is acquired in plants and that this method is more practical for the surface inoculation of large nonpackaged deli meat products. It is important to note that the contact inoculation method does not undercut the safety of process evaluation, since the typical sponge-delivered contact inoculum for our deli products resulted in L. monocytogenes levels of ca. 10^9 CFU per product piece tested, and all products were inoculated in this manner on several sides. There is no conceivable way that fully cooked product could acquire such high levels of Listeria through contact unless growth-permissive conditions were involved.

In an additional roast beef study involving only contact inoculation, we examined the effect of radiant heat surface pasteurization on whole and half rounds of roast beef positioned in the oven with the cut side facing either forward or to the side, and we compared frozen-and-thawed roast beef product processed by radiant heat pasteurization alone with that processed by radiant heat pasteurization in combination with postpackage pasteurization (Fig. 5). Radiant heat pasteurization of both whole and half rounds of fresh refrigerated roast beef (regardless of position) as well as whole logs of corned beef resulted in similar L. monocytogenes reduction levels (2.15 to 2.45 log cycles) (Fig. 5A). However, radiant heat pasteurization of frozen-and-thawed roast beef resulted in lower reduction levels (1.5 log cycles), presumably owing to the destruction of meat cells, leading to an increase in the “juiciness” of the roast beef after thawing (Fig. 5B). When frozen-and-thawed roast beef was processed via short-term postpackage pasteurization (for 60 and 90 s), freezing and thawing together with the short processing time was also found to result in low L. monocytogenes reduction levels (Fig. 5B). However, whether roast beef was fresh, or frozen and thawed, the use of the combination of 60 s of radiant heat pasteurization followed by 60 or 90 s of postpackage pasteurization (200°F) resulted in reduction levels of >3 log cycles (Fig. 5A and 5B), which would have required 10 min to achieve with postpackage pasteurization alone. It should be noted that for fresh roast beef, the combination of 60 s of radiant heat...
pasteurization and 60 s of postpackage pasteurization resulted in larger reductions than a slightly longer process (60 s of radiant heat pasteurization and 90 s of postpackage pasteurization) did for frozen-and-thawed roast beef (Fig. 5B). The reduction in the time required for the postpackage pasteurization phase of the combination process (60 or 90 s) provided the additional benefit of generating little or no purge compared with what we have observed in trials involving longer postpackage pasteurization times (4, 6, 8, and 10 min) (7). These data demonstrate the effectiveness of a short-duration combined process that provides additional processing after final packaging with no further handling of the product in significantly reducing pathogen levels. However, the heat-treated product may need to be chilled prior to boxing, since the surface quarter inch has been heated.

The results of the present study indicate that radiant heat prepackage surface pasteurization, postpackage surface pasteurization (7), or a combination of the two processes can alleviate potential Listeria contamination on RTE deli meat surfaces with minimal effects on product quality. The benefits of such a process should be considered with respect to the potential for a product’s acquisition of contamination in plant environments in which RTE products are manufactured and packaged and in comparison with those of preexisting processing lines that do not include additional intervention steps. The potential savings of such a process must be measured in view of recent large recalls (and, worse, illnesses and deaths) that have been attributed to the manufacture and distribution of contaminated products. The data provided herein demonstrate that new processing strategies and microbial interventions that can provide safe products for the benefit of consumers and processors alike are currently available.

ACKNOWLEDGMENTS

Support for this research was provided in part by the Oklahoma Agricultural Experiment Station, Oklahoma State University, Stillwater, Okla. We also thank Unitherm Foodsystems Inc., Stevison Ham Co., Vincent Giordano Corp., J. Freirich Co., Bar-S Foods Co., Sara Lee Corp., and Cargill Foods for technical discussions, products, and/or financial support of this research. We also thank William Robertson, Brad Jordan, Suparna Mitra, and Bill Quimby for assistance with the plating of samples.

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