Fate of *Listeria monocytogenes* in Commercial Ham, Formulated with or without Antimicrobials, under Conditions Simulating Contamination in the Processing or Retail Environment and during Home Storage

ALEXANDRA LIANOU, IFIGenia GEORNARAS, PATRICIA A. KENDALL, KEITH E. BELK, JOHN A. SCANGA, GARY C. SMITH, AND JOHN N. SOFOS

1Center for Red Meat Safety, Department of Animal Sciences, Colorado State University, Fort Collins, Colorado 80523-1171; and 2Department of Food Science and Human Nutrition, Colorado State University, Fort Collins, Colorado 80523-1571, USA

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ABSTRACT

Commercial cured ham formulated with or without potassium lactate and sodium diacetate was inoculated with *Listeria monocytogenes* and stored to simulate conditions of processing, retail, and home storage. The ham was sliced, inoculated with a 10-strain composite of *L. monocytogenes* (1 to 2 log CFU/cm²), vacuum packaged, and stored at 4°C to simulate contamination following lethality treatment at processing (first shelf life). After 10, 20, 35, and 60 days of storage, packages were opened, samples were tested, and bags with remaining slices were reclosed with rubber bands. At the same times, portions of original product (stored at 4°C in original processing bags) were sliced, inoculated, and packaged in delicatessen bags to simulate contamination during slicing at retail (second shelf life). Aerobic storage of both sets of packages at 7°C for 12 days was used to reflect domestic storage conditions (home storage). *L. monocytogenes* populations were lower (*P* < 0.05) during storage in ham formulated with lactate-diacetate than in product without antimicrobials under both contamination scenarios. Incubation of ham without lactate-diacetate allowed prolific growth of *L. monocytogenes* in vacuum packages during the first shelf life and was the worst case contamination scenario with respect to pathogen numbers encountered during home storage. Under the second shelf life contamination scenario, mean growth rates of the organism during home storage ranged from 0.32 to 0.45 and from 0.18 to 0.25 log CFU/cm²/day for ham without and with lactate-diacetate, respectively, and significant increases in pathogen numbers (*P* < 0.05) were generally observed after 4 and 8 days of storage, respectively. Regardless of contamination scenario, 12-day home storage of product without lactate-diacetate resulted in similar pathogen populations (6.0 to 6.9 log CFU/cm²) (*P* ≥ 0.05). In ham containing lactate-diacetate, similar counts were found during the home storage experiment under both contamination scenarios, and only in 60-day-old product did samples from the first shelf life have higher (*P* < 0.05) pathogen numbers than those found in samples from the second shelf life. These results should be useful in risk assessments and for the establishment of “sell by” and “consume by” date labels for refrigerated ready-to-eat meat products.

Delicatessen meat and poultry products contaminated with *Listeria monocytogenes* have been implicated as vehicles in numerous illnesses and fatalities in three major listeriosis outbreaks in the United States (11, 12, 14). In the risk assessment conducted by the U.S. Food and Drug Administration and the U.S. Department of Agriculture Food Safety and Inspection Service (FSIS), deli meats were identified as having the highest predicted relative risk for listeriosis among 23 categories of ready-to-eat (RTE) foods on both a per serving and per annum basis (47). The incidence, persistence, and transmission of *L. monocytogenes* at the production level have been documented (31, 39), and various prevalence rates of the pathogen have been reported in different RTE products collected from processing or retail establishments (22, 28, 48–50, 52). Gombas et al. (22) determined the incidence and concentrations of *L. monocytogenes* in RTE foods collected from retail markets in the United States and reported a prevalence of 0.89% in sliced luncheon meats; these meats and smoked seafood accounted for the majority of *L. monocytogenes*-positive samples with concentrations higher than 10³ CFU/g.

Contamination of RTE foods with *L. monocytogenes* can occur at various places in the food production chain, and the transmission dynamics of the pathogen in both the food-processing and retail environments have attracted considerable attention in recent years (26). The important role of retail establishments in the transmission of the pathogen has been demonstrated by surveillance and microbiological investigations (22, 43, 48) and with molecular subtyping techniques (42, 49). Slicers and other utensils used in these environments can serve as sources of pathogen cross-contamination of RTE meat and poultry products (24, 25, 30, 51). The contribution of the home environment and consumer food handling practices to the transmission of the organism and the incidence of listeriosis also has been demonstrated (8, 27, 36). Among reported food handling errors, improper temperature control and extended home storage...
have been identified as the most critical factors associated with the risk of foodborne listeriosis (18, 47, 53).

The fate of L. monocytogenes in RTE meat and poultry products depends on the type of product and its intrinsic properties (e.g., pH, water activity, and nitrite concentration), the initial concentrations of the organism, the storage temperature, and the natural microflora of the product (7, 10, 16, 21, 23, 34). The antilisterial activity of compounds that are generally recognized as safe, particularly sodium or potassium salts of lactic acid and sodium acetate or diacetate when used as ingredients in RTE meat products, has been documented (4–6, 20, 33, 37, 44). The information provided previously indicates that when assessing consumer exposure to L. monocytogenes or evaluating the effectiveness of antilisterial interventions, factors such as potential contamination routes in the food chain and handling and storage conditions preceding consumption must be considered. However, in most published studies, the behavior of the pathogen during vacuum-packaged storage has been evaluated, and only limited information is available on L. monocytogenes behavior under handling and storage conditions similar to those encountered in retail and domestic environments.

The present study was conducted to assess the fate of L. monocytogenes in commercial ham formulated with or without potassium lactate and sodium diacetate under two contamination scenarios and simulated home storage conditions. Product was inoculated under conditions chosen to simulate contamination at two different points in the food chain, i.e., the processing and retail environments, and home storage was simulated by aerobic storage of sliced product for 12 days at a mildly abusive temperature (7°C). Growth trends of the natural microflora of the product under the above conditions also were evaluated because the composition and concentrations of these microbes may affect the growth of the pathogen and the storage period during which the product remains acceptable to the consumer.

MATERIALS AND METHODS

L. monocytogenes strains. The 10-strain L. monocytogenes composite used in this study included strains 558 (serotype 1/2, pork meat isolate), NA-1 (serotype 3b, pork sausage isolate), N-7150 (serotype 3a, meat isolate), N1-225 and N1-227 (serotype 4b, clinical and food isolates, respectively, associated with the same outbreak (11)), R2-500 and R2-501 (serotype 4b, food and clinical isolates, respectively, associated with the same outbreak (13)), and R2-763, R2-764, and R2-765 (serotype 4b, clinical, food, and environmental isolates, respectively, associated with the same outbreak (14)). Strains N1-225, N1-227, R2-500, R2-501, R2-763, R2-764, and R2-765 were kindly provided by Dr. Martin Wiedmann (Cornell University, Ithaca, N.Y.). Selection of strains was based on their growth behavior in culture broth, as evaluated in a previous study conducted in our laboratory (29), and on their origin. Strains with robust growth characteristics at 4°C and that have been associated with outbreaks were primarily chosen in compliance with recommendations of the National Advisory Committee on Microbiological Criteria for Foods (35). All strains were available as refrigerated (4°C) cultures on slants of tryptic soy agar (TSA; Difco, Becton Dickinson, Sparks, Md.) supplemented with 0.6% yeast extract (YE; Acumedia, Baltimore, Md.), and working cultures were stored in this form and subcultured monthly. Strains were activated by transferring a single colony from fresh PALCAM agar (Difco, Becton Dickinson) plates into 10 ml of tryptic soy broth (TSB; Difco, Becton Dickinson) supplemented with 0.6% YE and incubating at 30°C for 24 h. Activated cultures were subcultured (0.1 ml) into 10 ml of fresh TSBYE and incubated at 30°C for 24 h.

Inoculum preparation. For inoculum preparation, 24-h cultures of each strain were centrifuged and washed separately as described in previous studies (19, 20). The harvested cells from each culture were resuspended separately in 10 ml of ham extract prepared from product of the same lot as that used in the study (but kept frozen during the study at −20°C). To prepare the extract, ham without potassium lactate–sodium diacetate was homogenized (Masticator, IUL Instruments, Barcelona, Spain) with distilled water for 2 min to yield a 10% (wt/wt) suspension of the product, which was subsequently passed twice through cheesecloth, autoclaved for 15 min, and cooled to ambient temperature (25°C) before use. The cultures suspended in ham extract were stored at 7°C for approximately 3 days (60 to 72 h) to allow for acclimatization of the cells to a low-temperature food environment and then combined and serially diluted in freshly prepared ham extract to yield an inoculum count of 1 to 2 log CFU/cm² when 0.1 ml of inoculum was applied to each side of a piece of sliced ham. The pH of the product extract used for inoculum preparation was measured both before (pH 6.43 ± 0.04) and after (pH 6.46 ± 0.04) autoclaving using a digital pH meter with a glass electrode (Denver Instruments, Arvada, Colo.).

Product inoculation. Commercial ham formulated without or with potassium lactate and sodium diacetate was used within 5 days of production. The product was cured with water, salt, sugar, sodium phosphates, sodium erythorbate, and sodium nitrite. The fat and moisture contents of the product were determined according to the AOAC International official methods (960.39 and 950.46B, respectively) (1). The fat content of product with and without lactate-diacetate was 3.4% ± 0.6% and 3.2% ± 0.2%, respectively, and the moisture content was 72.6% ± 5.5% and 73.9% ± 0.4%, respectively. Before inoculation, ham was sliced (approximately 3 mm thick), and slices were cut into pieces (5 by 5 cm, 25 cm² per side). Pieces were inoculated under a biological safety cabinet. The inoculum (0.1 ml) was spread on one side of each piece with a sterile bent glass rod, the pieces were left to stand for 15 min at 4°C for attachment of the inoculum, and then the other side was inoculated following the same procedure.

Twelve pieces of inoculated product were stacked on top of each other and placed in vacuum bags (20 by 25 cm, 3 mil std barrier; Nylon/PE vacuum pouch, Koch, Kansas City, Mo.), vacuum packaged (Hollymatic Corp., Countryside, Ill.), and stored at 4°C to simulate contamination of product during manufacturing (first shelf life [FSL]). At 10, 20, 35, and 60 days of storage, packages were opened, pieces were tested (microbiological and chemical analyses), and bags with remaining pieces were reclosed by folding and secured with rubber bands; this process simulated home use of presliced packaged ham. At the same time intervals, portions of the original unsliced product, which had been stored at 4°C in original processing vacuum packages, were sliced, cut, and inoculated as above. Twelve pieces of this product were stacked on top of each other, placed on delicatessen paper (20 by 27 cm; Glenvale Deli Wrap, Dixie Food Service, Georgia-Pacific, Atlanta, Ga.), and packaged in reclosable delicatessen bags (20 by 25 cm; Koch), simulating contamination during slicing and handling at retail (second shelf life [SSL]). In both cases (FSL and SSL inoculation), bags (i.e., vacuum bags that were opened
FIGURE 1. Inoculation of ham with Listeria monocytogenes under conditions simulating contamination in the processing (first shelf life [FSL]) or retail (second shelf life [SSL]) environment and storage under simulated home storage conditions. PL, potassium lactate; SD, sodium diacetate; 10-strain composite of L. monocytogenes (1 to 2 log CFU/cm²); microbiological and chemical analyses.

and reclosed with rubber bands and delicatessen bags) were left at ambient temperature (25°C) for 90 min to simulate temperature abuse of the product (e.g., time lapse between purchase and home refrigeration). Bags were then stored at 7°C for 12 days (Fig. 1). The latter storage conditions (i.e., aerobic storage at a mildly abusive temperature) were applied to simulate home storage of RTE ham that is prepackaged or is sliced and packaged at retail.

Microbiological analyses. Samples were analyzed on days 0, 10, 20, 35, and 60 of refrigerated (4°C) vacuum-packaged storage and on days 0, 4, 8, and 12 of aerobic storage at 7°C following 10, 20, 35, and 60 days of vacuum-packaged storage of the product (either sliced and inoculated or unsliced) (Fig. 1). Two consecutive pieces from each bag were transferred aseptically to a sterile 24-oz (720-ml) bag (Whirl-Pak, Nasco, Modesto, Calif.) containing 50 ml of maximum recovery diluent (MRD; 0.85% NaCl and 0.1% peptone) and shaken vertically 30 times (4, 40). Appropriate serial dilutions in 0.1% buffered peptone water (Difco, Becton Dickinson) were surface plated on the following media: TSAYE for the enumeration of total mesophilic and total psychrotrophic microbial populations, PALCAM agar for the enumeration of L. monocytogenes, and rose bengal chloramphenicol agar (RBC; Difco, Becton Dickinson) for the enumeration of yeasts and molds. Presumptive lactic acid bacteria (LAB) were enumerated by pour plating in deMan Rogosa Sharpe agar (MRS; Biotrace International Inc., Bothell, Wash.) as described in previous studies (4, 5). Colonies were counted after incubation at 25°C for 72 h (TSAYE for total mesophiles and MRS) or 7 days (RBC), at 30°C for 48 h (PALCAM), or at 7°C for 14 days (TSAYE for total psychrotrophs).

Measurement of pH and aw. After samples were processed for plate culture, each sample was homogenized (Masticator, IUL Instruments) for 2 min, and the pH of the homogenate was measured using a digital pH meter with a glass electrode (Denver Instruments). At 0, 10, 20, 35, and 60 days of vacuum-packaged storage (4°C), a ham piece was transferred to a Whirl-Pak bag containing distilled water (1:10), and the pH was measured as before. Water activity (aw) of ham was measured during vacuum-packaged storage using an AquafLab (model series 3, Decagon Devices Inc., Pullman, Wash.) water activity meter (19, 20).

RESULTS AND DISCUSSION

Fate of L. monocytogenes under the FSL contamination scenario. As expected, the fate of L. monocytogenes in FSL product during aerobic storage at 7°C was affected by its behavior during the preceding vacuum-packaged storage at 4°C. Counts of the organism on 10, 20, 35, and 60 days of vacuum storage were considered the day 0 counts of subsequent home storage (Fig. 2). In ham without lactate-diacetate, L. monocytogenes populations increased from 1.4 log CFU/cm² on day 0 to 7.0 log CFU/cm² on day 35 of storage in vacuum packages (4°C) and remained at this level throughout the 60-day storage period. Because product without antimicrobials supported prolific growth of the pathogen during vacuum-packaged storage, populations reached within 4 days of subsequent home storage ranged from 5.2 to 6.7 log CFU/cm² (Fig. 2). Therefore, manufacturers that do not use any antimicrobial intervention and rely solely on sanitation for control of this organism may also need to restrict the shelf life of such products in case they become contaminated.

In FSL product formulated with lactate-diacetate, L. monocytogenes populations were lower (P < 0.05) than those in product without antimicrobials both during storage in vacuum packages, confirming findings of previous studies (4–6, 20, 33, 37), and during home storage (Fig. 2). Significant increases in pathogen counts were observed only after 8 days of home storage, with the organism reaching 3.2 to 5.2 log CFU/cm², depending on the age of the product (length of vacuum storage preceding home storage). However, in product that was stored aerobically after 60 days of storage in vacuum packages, pathogen counts of 4.3 log CFU/cm² were present even on day 0 of home storage. Indications of virulence variation among subtypes of L. monocytogenes (15) and the ability of relatively low numbers (10² to 10⁴ cells per g) to cause human infections (17) render counts of this organism such as those obtained in this study potentially hazardous for sensitive individuals. These findings indicate that lactate-diacetate, when used at levels not sufficient to completely inhibit growth of L. monocytogenes, may not prevent consumer exposure to increasing concentrations of the pathogen. Such concentrations, assuming postprocessing contamination of ham at the production level (i.e., at the beginning of its shelf life), may
be encountered either during prolonged domestic storage of opened packages of the product or during extended vacuum-packaged storage of the product before it reaches the consumer. Therefore, higher concentrations of antimicrobial compounds (45) or employment of additional antilisterial hurdles during product slicing and/or packaging (3, 4, 20, 37) may be required for better consumer protection. Establishment of short “consume by” dates (e.g., no more than 4 days after opening of the package) may also be useful.

**Fate of L. monocytogenes under the SSL contamination scenario.** *L. monocytogenes* populations during home storage were lower \((P < 0.05)\) in ham containing lactate-diacetate than in product without antimicrobials, and observed increases in initial pathogen counts \((1.4 \text{ to } 1.7 \text{ log CFU/cm}^2)\) during the 12-day storage period ranged from 2.1 to 2.9 and from 3.9 to 5.3 log CFU/cm², respectively \((\text{Fig. } 2)\). Mean growth rates of the organism ranged from 0.32 to 0.45 and from 0.18 to 0.25 log CFU/cm²/day for ham without and with lactate-diacetate, respectively \((\text{Table 1})\), and significant \((P < 0.05)\) increases in pathogen counts were generally observed after 4 and 8 days of home storage, respectively \((\text{Fig. } 2)\). Growth rates of the organism during home storage were not affected \((P \geq 0.05)\) by age of the product \((\text{length of vacuum storage of original product before slicing and inoculation})\) both in product with and without lactate-diacetate \((\text{Table 1})\). This finding may be explained by the fact that the natural microflora of unsliced ham did not change noticeably during previous vacuum-packaged storage \((4^\circ C)\), as indicated by the total microbial populations on day 0 of home storage \((\text{Fig. } 3)\). These observations suggest that potential contamination of ham at retail during slicing and repackaging or at home \((i.e., \text{con-})\)
TABLE 1. Growth rates (GR) of L. monocytogenes on the surface of ham with or without potassium lactate–sodium diacetate

<table>
<thead>
<tr>
<th>Days of vacuum storage</th>
<th>Without lactate-diacetate</th>
<th>With lactate-diacetate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GR (log CFU/cm²/day)</td>
<td>r² b</td>
</tr>
<tr>
<td>10</td>
<td>0.32 ± 0.08 A a</td>
<td>0.882</td>
</tr>
<tr>
<td>20</td>
<td>0.44 ± 0.02 A a</td>
<td>0.998</td>
</tr>
<tr>
<td>35</td>
<td>0.36 ± 0.09 A a</td>
<td>0.946</td>
</tr>
<tr>
<td>60</td>
<td>0.45 ± 0.04 A a</td>
<td>0.997</td>
</tr>
</tbody>
</table>

a Unsliced ham that had been vacuum packaged and stored at 4°C was removed from packages at 10, 20, 35, and 60 days of storage, sliced, inoculated with L. monocytogenes at 1 to 2 log CFU/cm², and then stored at 7°C for 12 days. Values for growth rates are mean ± standard deviation (n = 6) as determined from cultures on PALCAM agar. Within a column, means lacking a common capital letter are significantly different (P < 0.05). Within a row, means lacking a common lowercase letter are significantly different (P < 0.05).

b Coefficient of determination for the linear regression.

Growth of L. monocytogenes during vacuum-packaged storage (4°C) of FSL ham was supported both in the absence and presence (albeit at slower rates) of lactate-diacetate (Fig. 2). Hence, depending on the application and efficacy of antilisterial interventions, contamination of ham at the processing level may result in similar or higher pathogen populations by the time the product reaches the consumer compared with product contaminated at the retail level. This finding is consistent with those of Gombas et al. (22), who reported that RTE manufacturer-packaged products tended to have higher concentrations of L. monocytogenes than did store-packaged products. Nevertheless, in addition to contamination levels, prevalence of the pathogen, consumption trends, and existing regulatory policies also can have an impact on the relative risk of foodborne listeriosis. Higher L. monocytogenes prevalence in store-packaged than in manufacturer-packaged luncheon meats has been documented (22) and is supported by research findings demonstrating the ability of the organism to persist in retail environments (42) and the high likelihood of these environments serving as a source of cross-contamination of RTE products (48, 49). The strict control of L. monocytogenes at the production level, which is needed to meet the zero tolerance policy and the requirements of the FSIS final rule (46), may render the food-processing environment a less likely source of the pathogen than the retail environment.

Effect of contamination scenario on L. monocytogenes populations. Comparative evaluation of all four situations assessed (i.e., two contamination scenarios of ham with or without lactate-diacetate) indicated that plant contamination (FSL) of ham without antimicrobials was the worst case scenario regarding L. monocytogenes concentrations to which consumers could be exposed during domestic storage of contaminated product. However, similar (P ≥ 0.05) pathogen populations (6.0 to 6.9 log CFU/cm²) were found in FSL and SSL ham without lactate-diacetate on day 12 of home storage (Fig. 2). Thus, regardless of contamination scenario, consumer food handling malpractices (i.e., prolonged storage at mildly abusive temperature) may constitute an additional risk factor for foodborne listeriosis, as also indicated by recent risk assessment data (53). Only limited information is available relative to domestic storage times. According to the findings of a consumer-based study in Sweden, the majority of the respondents reported that they stored opened packages of sliced ham for 3 days to 1 week; however, storage times as long as 2 weeks or based on the “best before” date on the product label or on personal judgment also were reported (32). In the presence of lactate-diacetate, pathogen populations throughout the 12-day aerobic storage period were similar (P ≥ 0.05) in FSL and SSL samples; significant differences (higher pathogen counts in FSL samples) were found only in 60-day-old product (Fig. 2). This finding suggests that ham formulated with lactate-diacetate, sliced, and vacuum packaged at the production level or sliced and repackaged at retail should pose similarly small (compared with product without antimicrobials) risk of listeriosis for consumers, provided that the shelf life of the product is not long (e.g., 60 days in this case).

Spoilage microflora. As expected, the spoilage microflora of ham consisted almost exclusively of psychrotrophic organisms, as indicated by the similar total mesophilic microbial counts (data not shown) and total psychrotrophic microbial counts (Fig. 3) obtained during vacuum-packaged and home storage in product both with and without lactate-diacetate.

Comparison of the counts obtained on TSAYE (Fig. 3), PALCAM agar (Fig. 2), and MRS (data not shown) revealed that LAB-like contaminants contributed to the spoilage of ham during home storage under both contamination scenarios in both the absence and the presence of antimicrobials. In general, changes in populations of presumptive LAB during home storage were variable, even within samples of the same product type and contamination scenario and at the same sampling time. This observation illustrates the random character of the natural microflora of this product, which can be subject to factors such as frequency, initial level, and type of contamination. Based on the counts on MRS, populations of LAB-like contaminants on FSL ham on day 60 of storage in vacuum packages (4°C) were 5.6 and 6.1 log CFU/cm² on product with and without lactate-diacetate, respectively. Growth of presumptive LAB during the preceding vacuum-packaged storage of ham under the FSL contamination scenario rendered them the predominant spoilage microflora of the product upon opening of the packages and initiation of home storage. In SSL ham, significant growth (P < 0.05) of LAB-like organisms was observed at 4 or 8 and at 4 or 12 days of home storage in product without and with lactate-diacetate, respectively. Although growth of LAB is selectively
FIGURE 3. Mean total psychrotrophic microbial populations (log CFU per square centimeter ± standard deviation, n = 6; grown on TSAE) on ham slices with or without potassium lactate–sodium diacetate that had been stored aerobically at 7°C for 12 days: (i) inoculation with *Listeria monocytogenes* (1 to 2 log CFU/cm²) followed by 10, 20, 35, and 60 days of vacuum-packaged storage at 4°C (first shelf life [FSL]) or (ii) slicing and inoculation of product with the pathogen (1 to 2 log CFU/cm²) after 10, 20, 35, and 60 days of vacuum-packaged storage of unsliced product at 4°C (second shelf life [SSL]).

Colonies growing on RBC were almost exclusively yeasts. Growth of yeasts was limited during vacuum-packaged storage, and final populations at 60 days were 2.5 and 2.1 log CFU/cm² on ham with and without lactate-diacetate, respectively (data not shown). Although changes in populations of yeasts were variable, their growth appeared to be favored during home storage under both contamination scenarios and was not inhibited in product formulated with lactate-diacetate, in agreement with findings reported previously (4, 5). During home storage of 35-day-old FSL ham, populations of yeasts were higher (*P* < 0.05) in product containing lactate-diacetate than in product without antimicrobials. For SSL inoculated ham, significant growth (*P* < 0.05) of yeasts was observed at 8 or 12 days of home storage in product both with and without lactate-diacetate.

**Chemical and physical properties.** Measurement of the pH of samples using both MRD and distilled water revealed that the differences were small (0.02 to 0.19 units) and that changes in pH during storage followed similar trends (data not shown). The initial *pH* values for samples suspended in MRD were 6.21 ± 0.08 and 6.28 ± 0.05 for ham with and without lactate-diacetate, respectively. The *pH* values for FSL ham with and without lactate-diacetate at 60 days of vacuum-packaged storage (4°C) were 6.23 ± 0.06 and 5.91 ± 0.11, respectively. In general, the *pH* of samples did not change considerably during home storage.
and significant decreases, when observed, were encountered after 8 or 12 days of storage.

The initial $a_w$ values were 0.957 ± 0.004 and 0.968 ± 0.005 for ham samples with and without lactate-diacetate, respectively. The lower $a_w$ ($P < 0.05$) of ham with lactate-diacetate compared with product without antimicrobials, both initially and throughout vacuum-packaged storage, can be attributed to potassium lactate (5, 6, 44). The $a_w$ of both sliced and unsliced product did not change considerably during storage in vacuum packages (data not shown).

The fate of $Listeria$ monocytogenes in cured ham under simulated home storage conditions (aerobic storage at 7°C) depended on the contamination scenario and the presence or absence of lactate-diacetate in the formulation of the product. Lower $Listeria$ monocytogenes populations were observed in ham containing lactate-diacetate than in product without antimicrobials under both contamination scenarios. Processing plant contamination of product without lactate-diacetate was the worst-case scenario with respect to pathogen concentrations encountered during aerobic storage. Based on the findings of this study, age of the product (length of refrigerated vacuum-packaged storage preceding aerobic storage) and/or length of aerobic storage might affect the influence of contamination scenario on pathogen concentrations unless interventions with proven listericidal or lysteriostatic activity are applied.

The results of the present study indicate that prevention of foodborne listeriosis requires the implementation of effective control measures throughout the food chain: at processing facilities, retail premises, and homes. The shelf life of RTE meat products must be based on the potential of each product to support growth of the pathogen and on the anticipated effectiveness of applied antilisterial interventions, as evaluated under various handling and storage conditions. The data collected here should be useful when conducting risk assessments and for the development or reevaluation of “sell by” and “consume by” date labels for refrigerated RTE meat products.

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