Control of *Listeria monocytogenes* on commercially-produced frankfurters prepared with and without potassium lactate and sodium diacetate and surface treated with lauric arginate using the Sprayed Lethality in Container (SLIC®) delivery method

A.C.S. Porto-Fetta, S.G. Campano, J.L. Smith, A. Oser, B. Shoyer, J.E. Call, J.B. Luchansky

**A R T I C L E  I N F O**

**Article history:**
Received 31 August 2009
Received in revised form 14 December 2009
Accepted 28 January 2010

**Keywords:**
Listeria monocytogenes
Antimicrobials
Pathogen
Food safety
Frankfurters
Ready-to-eat meats

**A B S T R A C T**

Viability of *Listeria monocytogenes* was monitored on frankfurters formulated with or without potassium lactate and sodium diacetate at a ratio of ca. 7:1 and treated with lauric arginate (LAE; 22 or 44 ppm) using the Sprayed Lethality in Container (SLIC®) delivery method. Without antimicrobials, pathogen numbers remained relatively constant at ca. 3.3 log CFU/package for ca. 30 d, but then increased to ca. 8.4 log CFU/package over 120 d. Regardless of whether or not lactate and diacetate were included, when treated with LAE, pathogen numbers decreased from ca. 3.3 log CFU/package to ca. 1.5 log CFU/package within 2 h, but then increased to 7.3 and 6.7 log CFU/package, respectively, after 120 d. When frankfurters were formulated with lactate and diacetate and treated with LAE, pathogen numbers decreased by ca. 2.0 log CFU/package within 2 h and remained relatively unchanged over the 120 d. These data confirm that LAE provides an initial lethality towards *L. monocytogenes* and when used in combination with reduced levels/ratio of lactate and diacetate as an ingredient for frankfurters provides inhibition throughout shelf life.

1. Introduction

As evidenced by a 2008 outbreak in Canada associated with ready-to-eat (RTE) deli-meats that resulted in 57 cases of listeriosis and 22 deaths (Anonymous, 2009), as well as the occurrence of several recent, albeit smaller, recalls of RTE meats across North America (USDA–FSIS, 2009), *Listeria monocytogenes* remains a considerable threat to public health. In response to costly product recalls and to outbreaks epidemiologically linked to RTE meat and poultry products, the United States Department of Agriculture–Food Safety and Inspection Service (USDA–FSIS) established policies to control *L. monocytogenes* on RTE meat and poultry products that requires manufacturers to validate that their processes achieve “zero tolerance”, as well as to include a post-process lethality treatment and/or to suppress outgrowth during shelf life (Anonymous, 2003b).

The antimicrobial effectiveness of organic acids and their salts, mostly lactate and diacetate, for controlling *L. monocytogenes* in RTE meats has been well established (Barmaplia et al., 2004; Bedie et al., 2001; Lu, Sebranek, Dickson, Mendonça, & Bailey, 2005; Mbandi & Shelef, 2002; Porto et al., 2002; Porto-Fett, Call, Muriana, Freier, & Luchansky, 2010, chap. 6; Samelis et al., 2005). Levels of lactates varying from 1.5% to 3.0%, added either alone or in combination with sodium diacetate levels ranging from 0.125% to 0.25%, are widely used by the meat industry as antilisterial ingredients in RTE meat and poultry products (Thompson, Carpenter, Martini, & Broadbent, 2008; Tompkin, 2002). It is well documented that these two food grade antimicrobials are quite effective at suppressing outgrowth of *L. monocytogenes* during an extended refrigerated shelf life, but are not that effective at delivering initial lethality towards the pathogen. Regarding the latter, previous studies evaluated the effectiveness of the Sprayed Lethality in Container (SLIC®) method to deliver different volumes and concentrations of lauric arginate (LAE) to the surfaces of various RTE meats to control *L. monocytogenes* (Luchansky, Call, Smith, Smith, & Oser, 2007; Luchansky, Smith, Oser, & Porto-Fett, 2009; Luchansky et al., 2005;
and commercially packaged as one lb packages (eight links per lb). The product, obtained directly from a producer/collaborator, was transported on ice to the USDA/ARS Eastern Regional Research Center (ERRC, Wyndmoor, PA) and stored at 4 °C for up to 120 d at 4 °C in a temperature-controlled incubator. The shelf life of frankfurters can range from 65 to 110 d for smaller to larger processors, respectively. The shelf life was extended to 120 d in the present study to quantify inhibition to the fullest extent possible. From our experience, it is expected and readily achievable for such products to be held at ≤4 °C over the duration of the projected shelf life.

2.4. Microbiological analyses

*L. monocytogenes* cells were recovered using the USDA/ARS package rinse method (Luchansky, Porto, Wallace, & Call, 2002). The outside surface of each package was wiped with an ethanol-soaked (70% vol./vol.) paper towel, and the package was opened with the aid of ethanol-sterilized scissors. Nineteen milliliters of Dey/Engley neutralizing broth (D/E broth; Difco, Becton, Dickinson Co., Franklin Lakes, NJ) were added, and the packages were massaged by hand for ca. 1 min before the resulting rinsate was transferred to a sterile 15-ml screw-capped conical centrifuge tube with the aid of a sterile pipette. Pathogen numbers were enumerated by directly spread-plating the rinsate or dilutions thereof onto duplicate polymyxin B, aclarfavin, lithium chloride, ceftazidime, esculin, ω-mannitol (PALCAM; Difco) agar plates, which were subsequently incubated at 37 °C for 48 h. When pathogen levels decreased to below the detection limit (≤1.40 log CFU/package) by direct plating, samples were enriched as previously described in Porto-Fett, Call, and Luchansky (2008). The total aerobic plate counts (TPC) and total lactic acid bacteria counts (LAB) were enumerated on days 0 and 120 by spread-plating 100 μl of the control rinsate or dilutions thereof onto brain heart infusion (BHI; Difco) and De Mann, Rogosa and Sharpe (MRS; Difco) agar plates, respectively. The MRS agar plates were incubated anaerobically (10.1% carbon dioxide, 4.38% hydrogen and balance nitrogen; Bactron IV Anaerobic/Environmental Chamber, Sheldon Manufacturing Inc., Cornelius, OR) at 37 °C for 48 h and the BHI agar plates were incubated at 30 °C for 72 h. Typical colonies of TPC on BHI, LAB on MRS, and *L. monocytogenes* on PALCAM were counted and bacterial numbers were expressed as log CFU/package.
2.5. Proximate composition

The proximate composition of frankfurters was determined, after ca. 9 months of storage at −20 ºC, by methods approved and described by the Association of Official Analytical Chemists (McNeal, 1990) as conducted by a commercial testing laboratory. Proximate composition analyses were separately performed on two representative samples (ca. 454 g total each) for the single batch prepared.

2.6. Statistical analyses

Data were analyzed with version 9.1.3 of the SAS statistical package (SAS Institute Inc., Cary, NC). Analysis of variance (ANOVA) was performed to evaluate the effects and interactions of type and concentration of antimicrobial on the initial lethality and the subsequent ability of potassium lactate and sodium diacetate and LAE to control the outgrowth of L. monocytogenes during extended storage at 4 ºC. Mean separations were performed using the Bonferroni-LSD method.

3. Results

3.1. Initial levels of L. monocytogenes, TPC, and LAB on commercial product

As a control, frankfurters were also tested for indigenous L. monocytogenes prior to inoculation with the pathogen cocktail; the pathogen was absent by both direct plating (<1.40 log CFU/package) and by enrichment (data not shown). The average initial levels of TPC and LAB on frankfurters formulated with no, low, or high levels of potassium lactate and sodium diacetate were ca. 2.3, 1.9, and 1.8 log CFU/package and 2.2, 1.6, and 1.3 log CFU/package, respectively. After 120 d of storage, the average levels of TPC and indigenous LAB for frankfurters with no, low, or high levels of potassium lactate and sodium diacetate increased to ca. 7.4, 6.4, and 6.3 log CFU/package and 7.0, 5.9, and 5.8 log CFU/package, respectively. Thus, inclusion of potassium lactate and sodium diacetate as ingredients resulted in ca. a 1.0-log CFU/package less increase in levels of TPC and LAB compared to otherwise similar frankfurters formulated without these antimicrobials.

3.2. Proximate composition of frankfurters and viability of L. monocytogenes on frankfurters

Results from proximate composition analyses (Table 1) revealed that there were no appreciable differences in the levels of ash, carbohydrates, fat, moisture, protein, salt, acidity, nitrite, water activity, and pH among treatments. As expected, however, results from proximate analyses revealed noticeable differences in lactate among products formulated with no (0.87%), low (1.79%), and high (2.44%) levels of lactate:diacetate (Table 1). In a previous study, about 0.96% of lactic acid was presented in frankfurters formulated without added potassium lactate (Porto et al., 2002). The 0.87% of lactate in control frankfurters is likely contributed by the postrigor production of lactic acid in the muscle tissue. While lactic acid concentration of post-mortem muscle may vary according to species, as well as due to pre- and post-slaughter conditions, 0.96% of lactate compare favorably with the levels observed in the present study, as well as the ca. 0.9% of lactic acid for post rigor mammalian muscle reported by Lawrie (1979). In fact, given that frankfurters contain about 70% meat and given that at ca. pH 5.9 that ca. 99.3% of the lactic acid would exist as the ionized species (lactate), then the measured amount and the expected amount of lactic acid are quite close. For the purposes of this study it is only important that there were quantifiable differences in the relative levels of lactate among frankfurters formulated with no, low, and high levels of lactate:diacetate. Differences between the target/ theoretical levels (0.68% or 1.36% lactate for "low" and "high", respectively) and the measured amounts of lactate could be attributed, at least in part, to cook shrink, chill shrink, the summation of the various salts of lactate that could be present, the time from manufacture through extended (frozen) storage until the analyses were conducted (ca. 9 months), the sensitivity/specificty of the analytical method, and/or the concentration of lactic acid in post rigor muscle.

The total number of samples (six samples from each treatment for each sampling day) that tested positive for the pathogen by direct plating and/or by enrichment are shown in Table 2. Inclusion of potassium lactate and sodium diacetate was more effective (P ≤ 0.05) in suppressing outgrowth of L. monocytogenes on the surface of frankfurters than for otherwise similar frankfurters formulated without these food grade chemicals. Moreover, regardless of whether or not potassium lactate and sodium diacetate were included in the formulation, when frankfurters were subsequently surface treated with either concentration of LAE, there were differences (P ≤ 0.05) at delivering an initial lethality towards the pathogen compared to samples that were not treated with LAE. However, no statistical difference (P ≥ 0.05) in lethality between the two concentrations of LAE tested was observed over 120 d of storage. More specifically, in the absence of any antimicrobials, pathogen numbers remained relatively constant at ca. 3.3 log CFU/package after 21 d, and then increased to ca. 8.4 log CFU/package over 120 d of storage. In frankfurters that did not contain added potassium lactate and sodium diacetate, but that were

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Levels of lactate–diacetate added to the formulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No (0% lactate–0% diacetate)</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>2.60 ± 0.007</td>
</tr>
<tr>
<td>Carbohydrates (%)</td>
<td>1.84 ± 0.25</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>22.75 ± 0.53</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>60.47 ± 1.02</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>12.36 ± 0.25</td>
</tr>
<tr>
<td>Sodium chloride (%)</td>
<td>1.76 ± 0.01</td>
</tr>
<tr>
<td>Potassium lactate (%)</td>
<td>0.87 ± 0.01</td>
</tr>
<tr>
<td>Phenolics (%)</td>
<td>&lt;1.0 ± 0.0</td>
</tr>
<tr>
<td>Sodium nitrite [ppm]</td>
<td>8.59 ± 0.71</td>
</tr>
<tr>
<td>Acidity, as lactic acid (%)</td>
<td>0.73 ± 0.04</td>
</tr>
<tr>
<td>Acidity, as acetic acid (%)</td>
<td>0.54 ± 0.00</td>
</tr>
<tr>
<td>Water activity</td>
<td>0.977 ± 0.001</td>
</tr>
<tr>
<td>pH</td>
<td>5.91 ± 0.04</td>
</tr>
</tbody>
</table>
Table 2
Viability of *L. monocytogenes* (log CFU/package) on frankfurters formulated with or without potassium lactate and sodium diacetate and then treated with LAE via SLIC® *(N = 2 trials; n = 3 packages per sampling interval).*

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Storage at 4 °C (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.04</td>
</tr>
<tr>
<td>No lactate/diacetate</td>
<td>3.32 ± 0.12a,b</td>
</tr>
<tr>
<td></td>
<td>6/6</td>
</tr>
<tr>
<td>No lactate/diacetate + 22 ppm LAE</td>
<td>1.28 ± 0.00b</td>
</tr>
<tr>
<td></td>
<td>4/6</td>
</tr>
<tr>
<td>No lactate/diacetate + 44 ppm LAE</td>
<td>1.17 ± 0.00b</td>
</tr>
<tr>
<td></td>
<td>4/6</td>
</tr>
<tr>
<td>Low lactate/diacetate</td>
<td>3.37 ± 0.02a</td>
</tr>
<tr>
<td></td>
<td>6/6</td>
</tr>
<tr>
<td>Low lactate/diacetate + 22 ppm LAE</td>
<td>1.25 ± 0.00b</td>
</tr>
<tr>
<td></td>
<td>4/6</td>
</tr>
<tr>
<td>Low lactate/diacetate + 44 ppm LAE</td>
<td>1.02 ± 0.00b</td>
</tr>
<tr>
<td></td>
<td>6/6</td>
</tr>
<tr>
<td>High lactate/diacetate</td>
<td>3.32 ± 0.01b</td>
</tr>
<tr>
<td></td>
<td>6/6</td>
</tr>
<tr>
<td>High lactate/diacetate + 22 ppm LAE</td>
<td>1.25 ± 0.06b</td>
</tr>
<tr>
<td></td>
<td>4/6</td>
</tr>
<tr>
<td>High lactate/diacetate + 44 ppm LAE</td>
<td>1.12 ± 0.09b</td>
</tr>
<tr>
<td></td>
<td>6/6</td>
</tr>
</tbody>
</table>

*a* Number of samples from which different lower case letters in common within a column are significantly *(P < 0.05)* different by the Bonferroni-LSID test.

*b* Number of samples from which *L. monocytogenes* was recovered by direct plating from among six total samples (two trials × three packages; six packages total per each treatment).

*c* Number of samples from which *L. monocytogenes* was recovered by enrichment from samples negative by direct plating.

*d* Number of samples from which *L. monocytogenes* was recovered by both direct plating and enrichment/total sampled (six total).
subsequently treated with 22 or 44 ppm of LAE, pathogen numbers decreased from ca. 3.3 log CFU/package to ca. 1.2 log CFU/package within 2 h, whereas after 120 d pathogen numbers increased to ca. 6.9 and 6.3 log CFU/package, respectively. When frankfurters were formulated with either low or high levels of potassium lactate and sodium diacetate, there was no appreciable reduction at time zero, but thereafter pathogen numbers decreased from ca. 3.3 log CFU/package to ca. 2.9 and 2.7 log CFU/package, respectively, within 120 d. However, when frankfurters were formulated with either low or high levels of potassium lactate and sodium diacetate and subsequently surface treated with 22 or 44 ppm of LAE via SLIC\(^\text{a}\), pathogen numbers decreased from ca. 3.3 log CFU/package to ca. 1.3 and 1.1 log CFU/package, respectively, within 2 h and remained relatively unchanged over the 120 d of refrigerated shelf life. These results validate that inclusion of potassium lactate and sodium diacetate as ingredients and the application of LAE on the surface as a post-process lethality treatment would effectively control \textit{L. monocytogenes} on frankfurters in the event of post-process contamination with this pathogen.

4. Discussion

Due to the ubiquity and persistence of \textit{L. monocytogenes} in various niches in the food processing environment, meat processors have implemented a variety of biological, chemical, and/or physical interventions to lessen the prevalence and levels of \textit{L. monocytogenes} on RTE meat products (Porto-Fett et al., 2010, chap. 6; Tompkin, 2002) with varying levels of success. In the present study, we demonstrated inhibition of \textit{L. monocytogenes} on frankfurters formulated with levels of lactate and diacetate that are quantifiably lower than levels commonly used by the meat industry for RTE meat products. Specifically, our results showed that addition of 0.68% lactate and 0.097% diacetate or 1.36% lactate and 0.19% diacetate decreased \textit{L. monocytogenes} numbers by ca. 0.4 to 0.8 log CFU/package over 120 d compared to the control treatment. In the absence of these food grade chemicals, pathogen numbers increased by ca. 5.0 log CFU/package over 120 d of refrigerated shelf life. These results compare favorably with the results of other studies, in that the inclusion of lactate and diacetate in RTE meats as ingredients suppressed outgrowth of \textit{L. monocytogenes} during extended refrigerated storage (Barmaplia et al., 2004, 2005; Bedie et al., 2001; Lu et al., 2005; Pal, Labuza, & Diez-Gonzalez, 2008; Porto et al., 2002; Samelis et al., 2002, 2005). Stekelenburg (2003) demonstrated a synergistic effect in preventing the outgrowth of \textit{L. monocytogenes} in Frankfurter sausage stored for 28 d at 4°C by adding potassium lactate and sodium diacetate [2–3% of (wt./wt.) solution]. However, when 3% of potassium lactate or 0.1% of sodium diacetate were added alone in the formulation, an increase of ca. 1.0 log CFU/g in pathogen numbers was observed during storage. In another study, Barmaplia et al. (2005) reported that inclusion of 1.8% sodium lactate and 0.125% sodium diacetate or 1.8% sodium lactate and 0.25% sodium diacetate as ingredients of pork bologna was more effective at suppressing the outgrowth of \textit{L. monocytogenes} after 90 d of storage at 4°C than when these food grade chemicals were added separately to the formulation. In addition, Mbandi and Shlef (2002) reported that when 2.5% sodium lactate and 0.2% sodium diacetate were added to the formulation of beef bologna, \textit{L. monocytogenes} numbers remained relatively unchanged after 45 d of storage at 5°C. In contrast, a 1.0- and 1.6-log CFU/g increase in pathogen numbers was observed during storage when either sodium lactate or sodium diacetate, respectively, were added separately to the formulation. Samelis et al. (2002) reported that inclusion of 1.8% sodium lactate and 0.25% sodium diacetate as ingredients in frankfurters suppressed outgrowth of \textit{L. monocytogenes} during storage for 120 d at 4°C. Thus, based on the parameters tested herein, it was somewhat expected that pathogen numbers would remain relatively unchanged over the refrigerated shelf life when frankfurters were formulated with typical levels of potassium lactate and sodium diacetate. However, the present study validates post-process inhibition when these two food grade chemicals are used as ingredients at a ratio of 7:1 (see below).

The levels of lactate and diacetate used in the present study, as well as the relative ratio of these two antimicrobials, are somewhat “atypical”. More specifically, a lactate to diacetate ratio of 14:1 and levels of 1.5–3.0% of lactate alone or in combination with 0.125–0.25% of diacetate on a wt./wt. basis in the formulation are commonly used by the meat industry (Thompson et al., 2008; Tompkin, 2002). In contrast, we used these chemicals as ingredients for frankfurters at a ratio of 7:1 and at levels of 0.68% or 1.36% of lactate along with 0.097% or 0.19% of diacetate in combination with LAE as applied via SLIC\(^\text{a}\). In addition to providing an initial lethality after packaging and a subsequent inhibition during storage, by using both lower levels and a lower ratio of lactate and diacetate in combination with LAE delivered via SLIC\(^\text{a}\), there could be an appreciable cost savings to a meat processor. Using frankfurters for illustrative purposes, we estimate the cost for including potassium lactate and sodium diacetate at a ratio of 7:1, that being an inclusion rate of ca. 0.68% lactate and ca. 0.097% diacetate, in combination with 22 ppm of LAE applied via SLIC\(^\text{a}\) as validated herein at ca. $0.01/lb less than an otherwise similar frankfurter formulated as such. The use of lower levels and ratios of diacetate and lactate may also be beneficial to processors because products formulated as such will retain the antilisterial potential of sodium diacetate, without the perceived untoward taste effects experienced by some consumers that are on occasion associated with the presence of higher levels of lactate and diacetate. Lastly, as pointed out by Seman, Quickert, Borger, and Meyer (2008), the use of a food grade chemical(s) as an ingredient, which they refer to as a formula-based intervention, has the advantage of being cost effective, as well as the added benefit of providing assurance that the antimicrobial is both present initially and potentially active once the package is opened.

As expected, in the absence of added potassium lactate and sodium diacetate, when frankfurters were surface treated with LAE, initial numbers of \textit{L. monocytogenes} were reduced by ca. 2.0 log CFU/package within 2 h of storage and pathogen numbers remained relatively unchanged for 30 d before subsequent outgrowth was observed over 120 d at 4°C. Several studies reported that inclusion of food grade chemicals, such as organic acids and their salts, as ingredients is effective at preventing outgrowth of \textit{L. monocytogenes} during an extended refrigerated shelf life of RTE meats (Bedie et al., 2001; Geornaras et al., 2006; Porto et al., 2002). It has also been well established that surface treatment of frankfurters and other RTE meats with LAE alone generates an initial lethality, but typically does not suppress outgrowth of the pathogen during extended refrigerated storage (Luchansky et al., 2005, 2007; Martin et al., 2009; Santiago-Connolly et al., 2008; Smith et al., 2009; Taormina & Dorsa, 2009). Therefore, it was not surprising that appreciable outgrowth of the pathogen was observed for frankfurters formulated without potassium lactate and sodium diacetate and/or for frankfurters treated with LAE alone. It should also be noted that the initial levels of LAB and
TPC were ca. <2.3 log CFU/package, thus indicating that the product was of high quality. At these relatively low starting levels, it is not likely that either by direct antagonism through the elaboration of organic acids and/or bacteriocins or via competitive exclusion that LAB or TPC would have any appreciable antilisterial activity. Thus, the observed antilisterial activity herein could be attributed primarily/solely to the effects of the lactates and LAE. These data also suggest that the levels/ratios of antimicrobials tested were not that effective at preventing outgrowth of TPC and/or LAB.

In the present study, inclusion of potassium lactate and sodium diacetate in the formulation in combination LAE applied via SLIC® resulted in both post-process inhibition and initial lethality, respectively, of L. monocytogenes on the surface of frankfurters stored at 4 °C. Our results are in general agreement with a recent publication by Martin et al. (2009) who evaluated the effectiveness of 1.8% potassium lactate and 0.13% sodium diacetate (14:1 ratio) or 2.1% potassium lactate and 0.15% sodium diacetate (14:1 ratio) added to the formulation of frankfurters that were subsequently treated with 22 ppm of LAE. These authors also confirmed that pathogen numbers remained relatively unchanged over the 156 d of refrigerated shelf life. We were able to deliver similar lethality and inhibition using lower levels and a lower relative ratio of these same antimicrobials. Moreover, results for our 120 d study were replicated twice, whereas the 156 d shelf life study by Martin et al. (2009) was based on a single trial. It is also generally well known that the efficacy of lactate and diacetate is dose dependent, both as individual and as combined components, and that the optimum dosage is also product dependent. To this end, we evaluated a “pork–water–beef” blend of frankfurters and Martin et al. tested a “three-species” product that included chicken as the primary ingredient. Validation that lower levels and ratios of these food grade chemicals are effective against L. monocytogenes in the present study will provide a considerable cost savings to the processor and ultimately to the consumer. This aspect is likely to be overlooked by food safety professionals in industry and academia, since lactate and diacetate are presently used at a ratio of 14:1 and typically at levels of 2.0:0.15%, respectively, and not at a ratio 7:1 and at levels as low 0.68:0.097% as evaluated herein. Lastly, and perhaps most importantly, Martin et al. did not perform proximate composition analyses to confirm that the target levels of each of the food grade chemicals were actually delivered to the single batch of frankfurters they tested. It is noteworthy to mention that the levels of salt, pH, and moisture may affect the efficacy of lactate and diacetate towards L. monocytogenes in RTE meat products (Houstma, Kant-Muermans, Rombouts, & Zwiertering, 1996; Legan, Seman, Milkowski, Hirshey, & Vandevene, 2004; Nerbrink, Borch, Blom, & Nesbakken, 1999; Tienungoon, Ratkowski, McMeekin, & Ross, 2000). Our results from proximate composition analyses (Table 1) revealed no appreciable differences in the levels of moisture, salt, and pH among treatments, thus, it is not likely that these parameters would have exhibited a confounding effect on the observed results. As detailed in Table 1 of our study, proximate compositional analyses showed marked differences between the lactate levels in each of the three formulations tested, thus, allowing us to definitively associate differences in formulation with pathogen viability. Collectively, these studies reinforce the importance of merging effective barriers against the pathogen, such as inclusion of selected food grade chemicals as ingredients followed by a subsequent post-processing treatment, to ensure for both adequate lethality and subsequent inhibition of L. monocytogenes on frankfurters and other RTE meats.

For the reasons defended herein, as well as clearly and concisely stated in text, our findings provide appreciably new information about these food grade chemicals while concomitantly validating a process for frankfurter production that has immediate value to processors.

In summary, our results validated that using a lower level of LAE applied via SLIC® in combination with lower levels and a lower ratio of lactates and diacetate than those typically used in the formulation of RTE meats, including frankfurters, displayed appreciable antilisterial activity. Future studies should be conducted to assess the potential impact, if any, of the levels of lactate/diacetate and LAE tested herein on the sensory and functional attributes of the finished products. Regardless, our findings should allow meat processors to meet existing regulatory policies, and possibly achieve Alternative 1 status (Anonymous, 2003a, 2003b), while producing a safer and more wholesome product at a lower cost.

Acknowledgments

Special thanks are extended to Nelly Osoria and Rosemary Martinjuk of the USDA/ARS/ERRC (Wyndmoor, PA) and to Glen Sansom of Kessler Foods, Inc. (Lemoyne, PA) for their assistance and/or technical expertise. Lastly, we respectfully dedicate this manuscript to our dear friend and long time colleague/collaborator, Jean L. Smith, who recently and unexpectedly passed away. Her many and valued contributions and her kindness and inspiring spirit are not forgotten.

References

and frankfurters surface treated with lauric arginate and stored at 4 °C for 24 hours. In Abstracts of the annual meeting of the International Association for Food Protection (P2-24), p. 148.


