Postprocessing Antimicrobial Treatments To Control *Listeria monocytogenes* in Commercial Vacuum-Packaged Bologna and Ham Stored at 10°C

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ABSTRACT

The antilisterial effect of chemical dipping solutions on commercial bologna and ham slices, inoculated (3 to 4 log CFU/cm²) after processing, was evaluated during storage in vacuum packages at 10°C. Samples were inoculated with a 10-strain composite of *Listeria monocytogenes* and subsequently immersed (25 ± 2°C) for 2 min in 2.5% acetic acid (AA), 2.5% lactic acid (LA), 5% potassium benzoate (PB), or 0.5% Nisaplin (commercial form of nisin, equivalent to 5,000 IU/ml of nisin) solutions, either singly or sequentially (Nisaplin plus AA, Nisaplin plus LA, or Nisaplin plus PB), and then vacuum packaged and stored at 10°C for 48 days. In addition to microbiological analysis, sensory evaluations were performed on uninoculated samples treated with AA, LA, or PB. Initial reductions (day 0) of the pathogen, compared with the controls, on bologna and ham samples treated with AA, LA, or PB ranged from 0.4 to 0.7 log CFU/cm². Higher (P < 0.05) initial reductions (2.4 to 2.9 log CFU/cm²) were obtained for samples treated with Nisaplin alone and when followed by AA, LA, or PB. *L. monocytogenes* populations on control bologna and ham samples increased from 3.4 log CFU/cm² (day 0) to 7.4 and 7.8 log CFU/cm², respectively, in 8 days at 10°C. Listericidal effects were observed for all treatments tested, except for Nisaplin applied on its own, during storage at 10°C. The sequential treatment of Nisaplin plus LA reduced *L. monocytogenes* to undetectable levels in both products at the end of storage. The sequential treatments were also found to inhibit growth of spoilage microorganisms. Sensory evaluations indicated that dipping (2 min) of ham samples in AA (2.5%), LA (2.5%), or PB (5%) led to lower sensory scores. However, since results of this study indicated that these treatments caused extensive listericidal effects, there is possibly a potential to reduce the levels of chemicals applied and still achieve adequate antilisterial activity without major negative effects on product quality.

Numerous sporadic and outbreak cases of foodborne illness have been linked to consumption of ready-to-eat (RTE) products contaminated with *Listeria monocytogenes*. Among 23 categories of RTE foods, deli meats were identified as products of highest risk for listeriosis on both a per serving and per annum basis (32). In a 4-year period (1998 to 2002), this pathogen was associated with three major, multistate outbreaks of listeriosis in the United States due to consumption of frankfurters and poultry deli meats (6–9). These outbreaks collectively resulted in approximately 183 illnesses, 27 deaths, and 12 miscarriages or stillbirths. Furthermore, *L. monocytogenes* has been involved in numerous recalls of potentially contaminated foods; more specifically, between 2000 and 2003, there have been at least 111 reported recalls of RTE meat and poultry products suspected of *L. monocytogenes* contamination (35).

The lethality treatment (cooking) that RTE meat and poultry products undergo eliminates the pathogen; however, recontamination may occur during postlethality exposure to the environment (e.g., peeling, slicing, and repackaging). Given the high risk of postprocessing contamination of RTE meat and poultry products with *L. monocytogenes* and the numerous recalls and deadly outbreaks associated with these products, the U.S. Food Safety and Inspection Service of the U.S. Department of Agriculture established an interim final rule to control *L. monocytogenes* in these products (34). Thus, establishments that produce RTE meat and poultry products that are exposed to the environment after the lethality treatment and that support growth of *L. monocytogenes* are required to comply with one of three alternatives to prevent product adulteration with the pathogen. Alternatives 1 and 2 require the use of a postlethality treatment (which may include antimicrobial agents) to reduce or eliminate *L. monocytogenes* and/or antimicrobial agents or processes to limit or suppress growth of the pathogen, whereas alternative 3 relies on sanitation measures and testing to control the pathogen in the postlethality environment (34). The industry is thus in need of information and options that are best suited to their processing methods to meet the requirements of the new regulation.

Antimicrobials agents have been shown to be valuable in the effort to control *L. monocytogenes* in RTE meat and poultry products. Numerous studies have been published on the use of chemical compounds with generally recognized as safe status as additives in the formulation of various meat products.
products to control the pathogen (1–3, 13, 18, 22, 26, 27, 30, 36). Most processors of RTE meat and poultry products in the United States include sodium or potassium lactate at levels of up to 2% combined with 0.05 to 0.15% sodium diacetate in the formulation of their products (31). Studies have also shown the effectiveness of postprocessing dipping (1, 13, 15, 22, 24, 28) and spraying (14) antimicrobial treatments against *L. monocytogenes*. Dipping or spraying treatments that have been tested include acids (acetic, citric, lactic, tartaric) and salts (sodium sorbate, potassium or sodium benzoate, sodium propionate, sodium acetate or diacetate, sodium lactate). Although a limited number of studies (24) have tested mixtures of antimicrobials for their antilisterial activity, to our knowledge, there have been no studies on the sequential application of dipping or spraying antimicrobial treatments for *L. monocytogenes* control in RTE meat products. Moreover, few of the published studies have examined the sensory effects of effective treatments on the products tested, which would provide some guidance to RTE meat processors.

Thus, the objectives of the present study were to investigate the antilisterial effect of chemical agents, applied as dipping solutions, on commercial bologna and ham slices inoculated after processing and stored in vacuum packages at 10°C to possibly be considered for use as alternatives under the recent regulatory requirements. The product storage temperature was representative of potential mild abuse during distribution and retail, as well as at the consumer level. Furthermore, evaluations were performed to determine the effect of selected antilisterial treatments on the sensory properties of the products.

**MATERIALS AND METHODS**

**Bacterial strains and inoculum preparation.** A 10-strain composite of *L. monocytogenes* was used in this study and included Scott A (serotype 4b, human isolate); NA-3 (serotype 4b), NA-19 (serotype 3b), 101M (serotype 4b), and 103M (serotype 1a), all isolated from pork sausage; 558 (serotype 1/2, pork meat isolate); and PVMI, PVMI2, PVMI3, and PVMI4 (pork variety meat isolates, serotype not known). The strains were activated and subcultured as described in previous studies (1, 27, 28).

To prepare the inoculum, 24-h cultures of all strains were combined and centrifuged (Eppendorf model 5810 R, Brinkmann Instruments Inc., Westbury, N.Y.) at 4,629 × g for 15 min at 4°C. The harvested cells were washed with 10 ml of phosphate-buffered saline (pH 7.4; 0.2 g of KH₂PO₄, 1.5 g of Na₂HPO₄·7H₂O, 8.0 g of NaCl, and 0.2 g of KCl in 1 liter of distilled water), centrifuged as previously described, and resuspended in 100 ml of fresh phosphate-buffered saline. The washed inoculum was then serially diluted in phosphate-buffered saline to obtain a target level of 3 to 4 log CFU/cm² when 0.1 ml of inoculum was applied to each side of a bologna or ham slice.

**Product inoculation.** Bologna and ham slices were obtained from a commercial manufacturer and were used for experiments within 5 days of production. The bologna formulation consisted of pork, beef, water, flavoring, salt, corn syrup, dextrose, sodium erythorbate, sodium nitrite, and oleoresin of paprika, whereas the ham was cured with water, salt, dextrose, sodium phosphates, sodium erythorbate, and sodium nitrite. Before inoculation, bologna slices (3 mm thick) were cut in half (58 cm² per side), whereas ham slices (1 to 2 mm thick) were cut into pieces (8 by 5 cm, 40 cm² per side). Slices were placed on a tray and inoculated under a biological safety cabinet. The inoculum (0.1 ml) was spread over one side of each slice with a sterile bent glass rod, left to stand for 15 min at 4°C to allow for inoculum attachment, and then inoculated on the second side using the same procedure.

**Application of treatments.** Following inoculation, slices were treated as follows: (i) no treatment (control); (ii) 2.5% acetic acid (AA; Mallinckrodt, Paris, Ky.); (iii) 2.5% lactic acid (LA; Sigma, St. Louis, Mo.); (iv) 5% potassium benzoate (PB; Sigma-Aldrich, Milwaukee, Wis.); (v) 0.5% Nisaplin (a commercial form of nisin; Aplin & Barret, Dorset, England), equivalent to 5,000 IU/ml of nisin; (vi) Nisaplin followed by AA; (vii) Nisaplin followed by LA; and (viii) Nisaplin followed by PB. The solutions were made up in sterile distilled water, except for Nisaplin, which was made up in 0.02 N HCl, and were applied at room temperature (25 ± 2°C). The pH values of the solutions were 2.53 ± 0.03 (AA), 2.00 ± 0.02 (LA), 7.56 ± 0.20 (PB), and 2.04 ± 0.29 (Nisaplin). All treatments were applied by immersing approximately 20 slices into 250 ml of solution for 2 min, followed by draining for approximately 1 min. For sequential treatments, treatments (vi) to (viii), slices were immersed in the first solution and then drained for 1 min before immersing in the second solution. After draining, three slices from each treatment were stacked on top of each other and placed in a vacuum bag (15 by 22 cm, 3 mil std barrier, Nylon/PE vacuum pouch, Koch, Kansas City, Mo.), vacuum packaged (Hollymatic Corp., Countryside, Ill.), and stored at 10°C for 48 days.

**Microbiological analyses.** Samples were microbiologically analyzed on days 0, 4, 8, 12, 20, 28, 36, and 48 of storage. One slice from each sample was aseptically transferred to a sterile 18-oz bag (Whirl-Pak, Nasco, Modesto, Calif.) to which 50 ml of 0.1% buffered peptone water (Difco, Becton Dickinson, Sparks, Md.) was added, and then vertically shaken 30 times (1, 28). After serially diluting each sample in buffered peptone water, 0.1 ml was surface plated onto tryptic soy agar (Difco) supplemented with 0.6% yeast extract (TSAYE; Acumedia, Baltimore, Md.) and PALCAM agar (Difco) for enumeration of total microbial and *L. monocytogenes* populations, respectively. Colonies were counted after incubation at 25°C for 72 h (TSAYE) and 30°C for 48 h (PALCAM agar). To obtain preliminary information on the predominant spoilage populations associated with samples from each treatment, during storage, random morphologically different colonies on TSAYE plates were tested for their Gram reaction (33). Gram-positive isolates were further subjected to the catalase test (33).

**pH and water activity measurements.** For pH measurements, a second slice from the same bag was diluted 10-fold with distilled water and homogenized (Masticator, IUL Instruments, Barcelona, Spain) for 2 min. Measurements of the slurry were taken with a Denver Instrument (Arvada, Colo.) pH meter and electrode. Water activity values, measured with an AquaLab (model series 3, Decagon Devices Inc., Pullman, Wash.) water activity meter, were only determined on day 0 samples. The calibration of the machine was checked with performance verification standards composed of saturated salt solutions (Decagon Devices), and all measurements were taken at room temperature (25 ± 2°C). To take a reading, samples were cut into pieces of <0.5 cm and placed evenly into an AquaLab sample cup, which was then placed inside the sample drawer of the instrument.

**Sensory evaluation.** Sensory evaluations were performed on bologna and ham slices that were (i) untreated (control) or treated...
for 2 min with (ii) 2.5% AA, (iii) 2.5% LA, or (iv) 5% PB. After application of the chemical treatments, slices were drained (1 min), placed into vacuum bags (oxygen transmission rate of 3 to 6 cm/m²²/24 h/atm [4.4°C, 0% relative humidity], Cryovac North America, Duncan, S.C.), vacuum packaged, and stored at 5°C until the next day, when they were evaluated. To identify treatment groups, samples were coded with random three-digit numbers. An untrained panel of 30 consumers was recruited from the Department of Animal Sciences at Colorado State University. A 9-point hedonic scale, where 1 indicates dislike extremely and 9 indicates like extremely, was used to evaluate the appearance, odor, flavor, and overall acceptability of the products. The color (1 indicating extremely pale and 9 indicating extremely dark) and texture (bologna, 1 indicating extremely soft and 9 indicating extremely firm; ham, 1 indicating extremely mushy and 9 indicating extremely chewy) of the products were also evaluated.

**Statistical analysis.** The study was conducted twice, with three samples analyzed per replication. Microbiological data were converted to log CFU per square centimeter before preliminary statistical analysis of fixed effects using the mixed model procedure of SAS (29), which indicated that counts depended on type of culture medium (TSAYE and PALCAM agar). Therefore, data were reanalyzed using an 8 (treatments) × 3 (sampling times) × 2 (replicates) factorial design. All statistical analyses were conducted with the SAS procedure for fixed effects and all interactions between fixed effects. Least squares means in bacterial populations between treatments and sampling times were separated using the analysis of variance mixed model procedure of SAS. All differences were reported at a significance level of alpha = 0.05.

**RESULTS AND DISCUSSION**

**Microbiological data.** The trends in antimicrobial activity against *L. monocytogenes* by the various treatments were similar for the two products evaluated in this study. *L. monocytogenes* populations on control (untreated) bologna and ham samples increased from 3.4 log CFU/cm² (day 0) to 7.4 and 7.8 log CFU/cm², respectively, in 8 days at 10°C (Figs. 1 and 2). The rapid growth of the pathogen was expected, because the products did not contain antimicrobials in the formulation or brine. In a similar study, *L. monocytogenes* on pork frankfurters formulated without antimicrobials grew from 2.5 to 7.6 log CFU/cm² in 12 days at 10°C (1).

All dipping treatments resulted in initial reductions of *L. monocytogenes* on both products compared with the untreated controls. The single treatments (i.e., AA, LA, or PB) led to initial reductions of 0.4 to 0.7 log CFU/cm² on bologna samples and 0.4 to 0.5 log CFU/cm² on ham samples. Similar reductions were reported by Samelis et al. (28) when pork bologna slices, formulated in a laboratory set-
ting, were dipped in 2.5 and 5% solutions of AA or LA or 5% PB for 1 min. In the present study, higher initial reductions of *L. monocytogenes* on both products were obtained after dipping in Nispalin alone or Nispalin followed by AA, LA, or PB. These treatments reduced (*P* < 0.05) pathogen levels by 2.4 to 2.8 log CFU/cm² and 2.6 to 2.9 log CFU/cm² on bologna and ham samples, respectively. Thus, reductions obtained for AA, LA, or PB, as single treatments, could have been in part due to a rinsing effect, whereas reductions obtained for Nispalin alone or in sequence with the other antimicrobials were clearly due to an antimicrobial effect. The latter effective treatments or antimicrobial treatments based on the tested solutions could potentially be considered as options for alternatives 1 and 2 of the new U.S. Food Safety and Inspection Service interim final rule (34) to reduce or eliminate the pathogen on RTE meat products contaminated after processing.

All antimicrobial treatments (except for Nispalin tested alone) exhibited inhibitory and even bactericidal effects during subsequent storage of samples at 10°C for 48 days. Populations of *L. monocytogenes* were reduced by 0.7 to 1.0 log CFU/cm² on bologna and ham samples treated with the single treatments (i.e., AA, LA, or PB) by the end of storage. These antimicrobial treatments could, therefore, be considered options for alternatives 1 and 2 of the interim final rule (34) for limiting or suppressing growth of the pathogen. In the study by Samelis et al. (28), no significant (*P* > 0.05) increases of the pathogen were obtained during a 120-day storage period at 4°C for bologna slices dipped in 2.5 or 5% AA and 5% PB or sodium diacetate. Only the 5% AA treatment, however, had a bactericidal effect by the end of storage (28). In an additional similar study (1), pork frankfurters formulated without antimicrobials as ingredients and dipped in 2.5% LA or AA for 2 min after processing resulted in initial reductions of *L. monocytogenes* of 0.7 to 2.1 log CFU/cm²; however, after 20 to 40 days of storage at 10°C, the pathogen grew to levels comparable to the nondipped control samples. The observed difference in the effectiveness of the same treatments during storage between our study and that of Barmadzil et al. (1) is most likely attributable to the nature of the products tested (sliced versus sausage type).

In the present study, Nispalin applied on its own, despite major initial (day 0) reductions in counts, allowed proliferation of the pathogen during storage. *L. monocytogenes* reached 7.5 log CFU/cm² in 28 days in bologna samples and 7.4 log CFU/cm² in 12 days in ham samples. However, when the Nispalin treatment was followed by an additional treatment, additional listericidal effects were observed for both products during storage. Samples treated initially with Nispalin and followed by AA showed additional reductions in *L. monocytogenes* populations of 1.0 and 0.7 log CFU/cm² in bologna and ham samples, respectively, by the end of the storage period. Similarly, populations on bologna and ham samples were reduced by 0.8 and 0.7 log CFU/cm², respectively, when samples treated with Nispalin were then exposed to PB. For bologna and ham samples treated with Nispalin followed by LA, *L. monocytogenes* was reduced to undetectable levels of <−0.4 and <−0.2 log CFU/cm², respectively, at the end of storage. Thus, the results are in agreement with previous findings that showed that *L. monocytogenes* is sensitive to nisin; however, the activity of this bacteriocin is diminished or lost during storage, possibly due to inactivation by food components (17, 20). Storage of the treated products at refrigeration (4°C) temperatures could enhance the antimicrobial effectiveness of nisin, as indicated by previous studies (11, 25). Furthermore, as shown in our study, nisin is more effective when used in combination with other antimicrobial interventions, such as chemical antimicrobials (5, 16, 17, 23), heat (4, 19), and CO₂ and NaCl (21). Thus, the data from the present study indicated that sequential treatments, such as those evaluated, may satisfy both requirements of alternative 1 of the interim final rule (34), because their application resulted in substantial reductions of initial populations of *L. monocytogenes* and, furthermore, led to bactericidal effects during storage, even at an abusive storage temperature. Processors, however, need to develop and validate their own formulations to fit their product specifications and expectations.

During storage, growth of total microbial populations on TSAYE, for control bologna and ham samples, followed patterns similar to those on PALCAM agar, indicating that most cells recovered from these samples were *L. monocytogenes* (Figs. 1 and 2). However, samples treated with AA, LA, PB, or Nispalin, applied singly, showed higher counts on TSAYE during storage, reflecting growth of spoilage microorganisms. Preliminary identification of random colonies from TSAYE plates of samples from these treatments indicated that lactic acid bacteria (gram-positive, catalase-negative) predominated on AA-, LA-, and PB-treated samples, whereas gram-negative bacteria predominated on Nispalin-treated samples. The absence of gram-positive bacteria from the predominant spoilage population in Nispalin-treated samples confirms their sensitivity to this bacteriocin on RTE meat products (10, 12). In the present study, in contrast to the single treatments, samples treated with the sequential treatments generally showed reductions of total microbial populations by the end of the 48-day storage period (Figs. 1 and 2). This indicated that the latter treatments were effective in controlling not only *L. monocytogenes* but also the gram-positive and gram-negative spoilage flora on these products.

**Chemical and physical properties.** The pH of untreated bologna and ham samples on day 0 was 6.13 and 6.38, respectively (Table 1). As expected, the organic acid treatments, applied singly and sequentially with Nispalin, led to a reduction of pH of both products; pH reductions were 1.31 to 1.41 for bologna samples and 1.75 to 2.12 for ham samples. Potassium benzoate and Nispalin treatments applied on their own and sequentially had no apparent effect on the product pH on day 0. Samples that were untreated and treated with Nispalin showed the greatest reductions in pH by the end of storage, reflecting bacterial growth of *L. monocytogenes* and/or spoilage microorganisms.

The water activity of control bologna and ham samples on day 0 was 0.963 ± 0.003 and 0.973 ± 0.001, respec-
TABLE 1. pH values of sliced commercial bologna and ham inoculated with *L. monocytogenes*, treated (2 min) with single or sequential antimicrobial dipping solutions, and vacuum packaged and stored at 10°C for 48 days

<table>
<thead>
<tr>
<th>Product</th>
<th>Day of storage</th>
<th>Control</th>
<th>Acetic acid (2.5%)</th>
<th>Lactic acid (2.5%)</th>
<th>Potassium benzoate (5%)</th>
<th>Nisaplin (0.5%) + acetic acid (2.5%)</th>
<th>Nisaplin (0.5%) + lactic acid (2.5%)</th>
<th>Nisaplin (0.5%) + potassium benzoate (5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bologna</td>
<td>0</td>
<td>6.13 ± 0.03</td>
<td>4.82 ± 0.14</td>
<td>4.78 ± 0.17</td>
<td>6.22 ± 0.03</td>
<td>6.01 ± 0.05</td>
<td>4.78 ± 0.10</td>
<td>4.72 ± 0.09</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>6.29 ± 0.14</td>
<td>4.87 ± 0.12</td>
<td>4.81 ± 0.19</td>
<td>6.35 ± 0.13</td>
<td>6.14 ± 0.23</td>
<td>4.79 ± 0.15</td>
<td>4.74 ± 0.24</td>
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<tr>
<td></td>
<td>8</td>
<td>6.08 ± 0.09</td>
<td>4.80 ± 0.07</td>
<td>4.81 ± 0.05</td>
<td>6.25 ± 0.04</td>
<td>6.05 ± 0.12</td>
<td>4.76 ± 0.08</td>
<td>4.76 ± 0.22</td>
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<tr>
<td></td>
<td>12</td>
<td>5.73 ± 0.15</td>
<td>4.85 ± 0.15</td>
<td>4.98 ± 0.10</td>
<td>6.30 ± 0.09</td>
<td>6.08 ± 0.18</td>
<td>4.81 ± 0.11</td>
<td>4.75 ± 0.21</td>
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<td></td>
<td>20</td>
<td>5.17 ± 0.06</td>
<td>4.79 ± 0.16</td>
<td>4.79 ± 0.16</td>
<td>6.11 ± 0.13</td>
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<td>28</td>
<td>4.88 ± 0.05</td>
<td>4.75 ± 0.04</td>
<td>4.85 ± 0.10</td>
<td>6.13 ± 0.20</td>
<td>5.58 ± 0.25</td>
<td>4.79 ± 0.13</td>
<td>4.71 ± 0.18</td>
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<tr>
<td></td>
<td>36</td>
<td>4.82 ± 0.16</td>
<td>4.88 ± 0.10</td>
<td>4.83 ± 0.12</td>
<td>5.80 ± 0.35</td>
<td>5.41 ± 0.19</td>
<td>4.78 ± 0.11</td>
<td>4.85 ± 0.22</td>
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<tr>
<td></td>
<td>48</td>
<td>4.73 ± 0.13</td>
<td>4.76 ± 0.05</td>
<td>4.88 ± 0.09</td>
<td>5.99 ± 0.29</td>
<td>5.09 ± 0.14</td>
<td>4.78 ± 0.13</td>
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<tr>
<td>Ham</td>
<td>0</td>
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<td>6.38 ± 0.08</td>
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<td>12</td>
<td>5.52 ± 0.07</td>
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<td>28</td>
<td>4.96 ± 0.10</td>
<td>4.56 ± 0.08</td>
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<td>6.23 ± 0.08</td>
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<td>3.99 ± 0.04</td>
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<td>36</td>
<td>4.92 ± 0.15</td>
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<td>4.54 ± 0.19</td>
<td>5.91 ± 0.39</td>
<td>5.21 ± 0.16</td>
<td>4.49 ± 0.22</td>
<td>4.34 ± 0.31</td>
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<td></td>
<td>48</td>
<td>4.76 ± 0.10</td>
<td>4.59 ± 0.07</td>
<td>4.46 ± 0.06</td>
<td>5.60 ± 0.14</td>
<td>5.15 ± 0.33</td>
<td>4.45 ± 0.11</td>
<td>4.30 ± 0.18</td>
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</tbody>
</table>

* Values are mean ± standard deviation; *n* = 6.
TABLE 2. Sensory evaluation ratings by an untrained panel for commercial sliced bologna that was untreated (control) or treated with acetic acid, lactic acid, or potassium benzoate, by dipping, for 2 min

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Control</th>
<th>Acetic acid (2.5%)</th>
<th>Lactic acid (2.5%)</th>
<th>Potassium benzoate (5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.0 ± 1.4 A</td>
<td>5.6 ± 1.2 A</td>
<td>5.5 ± 1.5 A</td>
<td>5.5 ± 1.4 A</td>
</tr>
<tr>
<td>Color&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.7 ± 1.2 A</td>
<td>4.8 ± 1.2 B</td>
<td>4.9 ± 1.1 B</td>
<td>4.7 ± 1.3 B</td>
</tr>
<tr>
<td>Odor&lt;sup&gt;d&lt;/sup&gt;</td>
<td>5.2 ± 1.6 A</td>
<td>3.9 ± 1.8 B</td>
<td>4.7 ± 1.6 A</td>
<td>4.9 ± 1.8 A</td>
</tr>
<tr>
<td>Flavor acceptability&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>6.0 ± 2.0 A</td>
<td>4.1 ± 2.1 B</td>
<td>4.9 ± 1.5 B</td>
<td>4.8 ± 1.9 B</td>
</tr>
<tr>
<td>Texture&lt;sup&gt;e&lt;/sup&gt;</td>
<td>5.5 ± 1.4 AB</td>
<td>5.3 ± 1.5 B</td>
<td>6.0 ± 1.2 A</td>
<td>5.0 ± 1.2 B</td>
</tr>
<tr>
<td>Overall acceptability&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.1 ± 1.4 A</td>
<td>4.3 ± 1.7 B</td>
<td>4.8 ± 1.4 B</td>
<td>4.7 ± 1.5 B</td>
</tr>
</tbody>
</table>

<sup>a</sup> Values are mean ± standard deviation; n = 30. Means within a row lacking a common letter are significantly different (P < 0.05).
<sup>b</sup> On a scale of 1 to 9 with 1 indicating extremely mushy and 9 indicating extremely chewy.
<sup>c</sup> On a scale of 1 to 9 with 1 indicating extremely pale and 9 indicating extremely dark.
<sup>d</sup> On a scale of 1 to 9 with 1 indicating dislike extremely and 9 indicating like extremely.
<sup>e</sup> On a scale of 1 to 9 with 1 indicating extremely soft and 9 indicating extremely firm.

Sensory analysis. The sensory attributes of bologna and ham treated by dipping in 2.5% AA, 2.5% LA, or 5% PB for 2 min were determined in controlling growth of L. monocytogenes in this study. It was decided not to perform sensory evaluations on products treated with the sequential treatments, because AA, LA, and PB were applied after Nisaplin in these treatments, and consequently, the sensory qualities of the products would be mainly affected by the final treatments.

Most panelists were college students (76.7%) between the ages of 21 and 34 years (73.3%) and were represented by almost equal numbers of men (53.3%) and women (46.7%). It was reported that 40 and 90% of them liked to eat bologna and ham, respectively. Furthermore, it was established that most panelists ate bologna one to six times per year (53.3%), whereas ham was consumed more frequently (one to three times per month by 43.3% of the panelists).

Under the conditions of this study, treating bologna and ham with AA, LA, or PB resulted in lower mean hedonic scores compared with untreated controls, especially for ham samples treated with PB (Tables 2 and 3). The standard deviations were expectedly high (1.1 to 2.1), since an untrained consumer-type panel was used for the sensory evaluations. Treatment of bologna with the antimicrobials resulted in mean color, flavor, and overall acceptability scores, which were 0.8 to 1.9 lower (P < 0.05) than the untreated bologna samples (Table 2). The AA treatment appeared to have the lowest odor, flavor, and overall acceptability scores compared with the control samples. However, the appearance of the bologna was not (P > 0.05) affected by any of the dipping treatments. Taking into account that 60% of the panelists had indicated that they did not normally like to eat bologna, the data for these panelists were removed and the results reevaluated. Although mean hedonic scores were, in general, slightly higher than those obtained for the total number of panelists, the trends obtained for each of the treatments were the same (data not shown). Treatment of ham with the antimicrobials resulted in mean odor, flavor, and overall acceptability scores, which were 2.1 to 4.5 lower (P < 0.05) than those of the untreated samples. Ham samples treated with PB received the lowest

TABLE 3. Sensory evaluation ratings by an untrained panel for commercial sliced ham that was untreated (control) or treated with acetic acid, lactic acid, or potassium benzoate, by dipping, for 2 min

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Control</th>
<th>Acetic acid (2.5%)</th>
<th>Lactic acid (2.5%)</th>
<th>Potassium benzoate (5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appearance&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.2 ± 1.6 A</td>
<td>5.3 ± 2.0 BC</td>
<td>5.8 ± 1.7 AB</td>
<td>4.7 ± 1.8 C</td>
</tr>
<tr>
<td>Color&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.7 ± 1.7 A</td>
<td>6.5 ± 1.8 A</td>
<td>6.2 ± 1.7 A</td>
<td>3.8 ± 1.9 B</td>
</tr>
<tr>
<td>Odor&lt;sup&gt;d&lt;/sup&gt;</td>
<td>6.6 ± 1.1 A</td>
<td>3.4 ± 1.8 C</td>
<td>4.5 ± 1.7 B</td>
<td>4.1 ± 1.8 B</td>
</tr>
<tr>
<td>Flavor acceptability&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>6.6 ± 1.4 A</td>
<td>2.1 ± 1.4 C</td>
<td>3.0 ± 2.0 B</td>
<td>2.7 ± 2.1 BC</td>
</tr>
<tr>
<td>Texture&lt;sup&gt;e&lt;/sup&gt;</td>
<td>4.8 ± 1.5 A</td>
<td>5.1 ± 1.9 A</td>
<td>4.5 ± 1.5 AB</td>
<td>3.7 ± 1.6 B</td>
</tr>
<tr>
<td>Overall acceptability&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.2 ± 1.4 A</td>
<td>2.5 ± 1.6 B</td>
<td>3.2 ± 2.0 B</td>
<td>2.6 ± 2.0 B</td>
</tr>
</tbody>
</table>

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