ABSTRACT The objective of this study was to determine the effect of antimicrobials on the survival and proliferation of *Listeria monocytogenes* in turkey breast rolls following electron-beam irradiation. Six antimicrobial additive treatments that include no preservatives (control), 0.1% potassium benzoate (PB), 2% sodium lactate (SL), 0.1% potassium benzoate plus 2% sodium lactate (PB + SL), 2% sodium lactate plus 0.1% sodium diacetate (SL + SDA), and 0.1% potassium benzoate, 2% sodium lactate, and 0.1% sodium diacetate (PB + SL + SDA) were used. Sliced turkey breast rolls were artificially inoculated with ~10⁶ cfu/cm² of 5-strain *L. monocytogenes* cocktails, then vacuum-packaged and irradiated at 0, 1.0, 1.5, 2.0, or 2.5 kGy. The radiation dose (kGy) that results in 90% reduction of viable cells for breast rolls, D₀ value, with various additive treatments ranged from 0.56 to 0.58 kGy. Adding PB (0.1%) or SL (2%) in turkey rolls failed to prevent *L. monocytogenes* from growing during refrigerated storage. In turkey rolls added with 2 (PB + SL or SL + SDA) or 3 (PB + SL + SDA) antimicrobial combinations had 2 or 3 wk of lag phases before *L. monocytogenes* growth, respectively. Irradiating turkey rolls, which were added with PB + SL or SL + SDA, at 1.0 kGy was effective in suppressing the growth of *L. monocytogenes* for about 6 wk when stored at 4°C. No growth of *L. monocytogenes* after irradiation occurred during 42 d of storage for 2.0 kGy irradiated breast rolls formulated with 0.1% PB + 2% SL, 2% SL + 0.1% SDA or 0.1% PB + 2% SL + 0.1% SDA, and 1.0 kGy irradiated turkey breast with 0.1% PB + 2% SL + 0.1% SDA. Sensory panelists found that low-dose irradiation (1.0 kGy) had no effect on the sensory characteristics of ready-to-eat turkey breast rolls. Including SL + SDA had slightly negative effect for nonirradiated turkey breast rolls, but the sensory characteristics of 1.0 kGy irradiated turkey roll containing SL + SDA was not significantly different from the others receiving 1.0 kGy irradiation. For microbial safety, PB + SL and SL + SDA antimicrobial treatments combined with 1.0 kGy or 2.0 kGy irradiation are a promising technology.

**Key words:** *Listeria monocytogenes*, electron-beam irradiation, sodium lactate, sodium diacetate, potassium benzoate

INTRODUCTION

Due to its high mortality rate (~25%) and economic losses caused by expensive product recalls (Mead et al., 1999; US Department of Health and Human Services, 2002), *Listeria monocytogenes* is a big food safety issue for the processed meat industry. For ready-to-eat (RTE) meat products, the most frequently applied hurdles such as thermal processing, vacuum packaging, refrigerated storage, and nitrite seem insufficient when it comes to *L. monocytogenes* due to its ubiquitous nature (Beresford et al., 2001), ability to grow at refrigerated temperature and anaerobic condition, and resistance to salt and nitrite (Lou and Yousef, 1999). Although *L. monocytogenes* can be killed during the thermal processing of RTE meats (Lemaire et al., 1989; Zaika et al., 1990), postprocessing contamination of RTE meat with *L. monocytogenes* during slicing and packaging is difficult to avoid. To ensure microbiological safety of RTE meat, it is essential to have additional intervention to control the growth of pathogen during refrigerated storage.

Formulating meat products with antimicrobial additives is one approach to suppress the growth of contaminated *L. monocytogenes* during storage, but they cannot destroy the pathogenic organisms that existed in RTE meat. Furthermore, including high concentration of antimicrobials such as sodium diacetate has a negative effect on the flavor of meat products (Stekelen-
burg and Kant-Muermans, 2001). Food irradiation is an effective postpackaging intervention technology to eliminate those contaminated *L. monocytogenes* in RTE meat products (Patterson et al., 1993; Thayer, 1995; Tarte et al., 1996; Thayer and Boyd, 2000; Clardy et al., 2002; Foong et al., 2004). Due to its negative effects on meat quality, only low dosages of irradiation are recommended in RTE meats (Zhu et al., 2003, 2004a). However, pathogens that survive low-dose irradiation can repair themselves, proliferate, and cause a health hazard during refrigerated storage (Gürsel and Gürakan, 1997; Foong et al., 2004), suggesting that an intervention in addition to low-dose irradiation would be necessary.

Antimicrobials were used in combination with irradiation to suppress the growth of *L. monocytogenes* following irradiation. Sommers and Fan (2003) used antimicrobials in combination with irradiation to suppress the growth of *L. monocytogenes* following irradiation. Gamma irradiation of *L. monocytogenes* suspended in sodium diacetate resulted in synergistic reductions of the microorganism, and supplementing sodium diacetate in beef bologna inhibited the proliferation of *L. monocytogenes*, which survived the irradiation process. Gamma irradiation at 3.0 kGy prevented the proliferation of *L. monocytogenes* and background microflora in bologna containing 0.07% sodium diacetate and 1% potassium lactate, and in bologna containing 0.15% sodium diacetate and 2% potassium lactate over 8 wk of storage at 9°C (Sommers et al., 2003). We found that turkey hams formulated with 2% sodium lactate + 0.1% sodium diacetate and 0.1% potassium benzoate +2% sodium lactate in combination with 1.0 kGy electron-beam irradiation was effective in suppressing the growth of *L. monocytogenes* for about 6 wk at 4°C, and 2.0 kGy irradiation was listeriostatic (Zhu et al., 2005). No studies were conducted to assess the effect of irradiation in combination with antimicrobials on the growth of *L. monocytogenes* in uncured turkey breast rolls, where *L. monocytogenes* may behave differently.

In the current study, potassium benzoate, sodium lactate, and sodium diacetate alone or in combination were tested for their ability in inhibiting the growth of *L. monocytogenes* in RTE turkey breast rolls following 1.0 kGy or 2.0 kGy electron-beam irradiation during 4°C storage. The effects of antimicrobial additives and irradiation on the sensory characteristics of turkey breast rolls were also assessed.

**MATERIALS AND METHODS**

**Bacterial Strains and Growth Conditions**

Five different *L. monocytogenes* strains (Scott A, H7969, H7596, H7762, and H7962) were used to inoculate sliced turkey breast rolls. Before inoculation, each stock culture was individually grown in 10 mL of tryptic soy broth (Difco Laboratories, Detroit, MI) supplemented with 0.6% yeast extract at 35°C for 18 h. Then, 1 mL of each strain was transferred individually to 100 mL of tryptic soy broth supplemented with 0.6% yeast extract and incubated at 35°C for another 18 h. Each strain was harvested, washed twice, and resuspended in sterile 0.1% (wt/vol) peptone water (Difco Laboratories). Inoculation cocktail was prepared by mixing equal volumes of the 5 strains, each with approximately equal numbers of bacteria.

**Preparation of RTE Turkey Meat Products**

Oven-roasted turkey breast rolls with different antimicrobial additives were freshly processed in the Meat Lab at Iowa State University. Six antimicrobial additive treatments include: 1) basic formula without any preservatives (control); 2) 0.1% potassium benzoate (PB); 3) 2% sodium lactate (SL); 4) 0.1% potassium benzoate and 2% sodium lactate (PB + SL); 5) 2% sodium lactate and 0.1% sodium diacetate (SL + SDA); and 6) 0.1% potassium benzoate, 2% sodium lactate, and 0.1% sodium diacetate (PB + SL + SDA). Antimicrobial additives were mixed with meat and other ingredients and then stuffed into large fibrous casings (φ = 11.5 cm). The rolls were heat-processed to 74°C internal temperature in an 84°C smoke house, chilled (4°C), sliced to 2-mm-thick pieces, and used for microbiological study. For sensory evaluation, only 4 antimicrobial additive treatments (control, PB + SL, SL + SDA, and PB + SL + SDA) are included. The RTE turkey breast rolls were manufactured on separate days and were sliced to 1.0-cm-thick pieces and were then vacuum-packaged.

**Inoculation of Test Samples**

The sliced turkey breast rolls (2-mm thick) were transferred to the microbiology laboratory and aseptically removed from the original bulk package into nylon-polyethylene bags (Koch Industries, Kansas City, MO; 3 mil standard barrier, O₂ < 0.6 cm³/m² per 24 h at 38°C), 1 slice per bag. Each sample slice was inoculated with 0.1 mL of *L. monocytogenes* cocktail to achieve a concentration at approximately 10⁶ cfu/cm² of surface area. Inoculated turkey roll samples were manually mixed for 30 s to evenly distribute the inoculum, then vacuum-sealed (Multivac A300/16, Sepp Haggenmüller KG, Wolfertschwenden, Germany), and kept refrigerated overnight before irradiation.

**Irradiation**

All samples were irradiated using the Linear Accelerator Facility (Circe I1IR, Thomson CSF Linac, Saint-Aubin, France) at Iowa State University. The vacuum-packaged inoculated samples of each additive treatment were divided randomly into 5 groups and irradiated at 0 (control), 1.0, 1.5, 2.0, or 2.5 kGy. Samples irradiated at 0, 1.0, and 2.0 kGy were stored at 4°C for up to 42
d. The number of *L. monocytogenes* survivors in inoculated samples receiving 0, 1.0, 1.5, 2.0, and 2.5 kGy irradiation were analyzed right after irradiation for D$_{10}$ value calculation. The number of *L. monocytogenes* survivors in inoculated samples receiving 0, 1.0, and 2.0 kGy irradiation were analyzed at a 7-d interval during 42 d of storage. Each antimicrobial and irradiation treatment has 3 replicates. For sensory analysis, the vacuum-packaged RTE turkey breast rolls of each additive treatment were randomly divided into 2 groups and irradiated at 0 (control) or 1.0 kGy. Sensory analysis was conducted 7 d after irradiation.

**Microbiological Analysis**

Each package was aseptically opened using an alcohol-sterilized scissors. One hundred milliliters of sterile 0.1% peptone was added to each meat sample (surface area ~100 cm$^2$) followed by pummeling at medium speed for 1 min in a stomacher. Samples were serially diluted with 0.1% peptone water and surface-plated (0.1 mL) in duplicate on modified Oxford agar plates to enumerate *L. monocytogenes*. Typical *Listeria* colonies on modified Oxford plates were counted after 48 h of incubation at 35°C.

**Calculation of Radiation D$_{10}$ Values**

The D$_{10}$ value, radiation dose (kGy) that results in 90% reduction of viable cells, was determined by plotting the log number of survivors per centimeter squared ($\log_{10}$ cfu/cm$^2$) versus irradiation dose (kGy). Linear regression curves were generated with SAS software (SAS, 2000). The D$_{10}$ value was calculated as the reciprocal of the absolute value of the slope of the regression line (Mendonca et al., 2004).

**Sensory Evaluation**

After irradiation, the sliced vacuum-packaged RTE turkey rolls (0 and 1.0 kGy) were directly transferred to the sensory evaluation laboratory at Iowa State University. Ten trained panelists participated in the evaluation of the sensory attributes of RTE turkey rolls. During training, panelists were familiarized with the sensory terms, the tasting techniques, and the computer software scoring system. Samples were evaluated for turkey roll-like aroma, off-aroma, turkey roll-like flavor, off-flavor, and saltiness. Testing was conducted in partitioned booths and under red fluorescent lights. A line scale (numerical value of 15 units) was used with descriptive anchors (none and high) at each end of the line. Data were collected by using a computerized sensory system (Compusense 5, v 4.0, Compusense Inc., Guelph, Ontario, Canada). Before presenting to sensory panelists, the samples were heated in a microwave oven to 60°C and labeled with random 3-digit codes. Two sessions were conducted. In each session, panelists received samples from each of the 8 treatments, with serving orders randomized. The measurements made on a given treatment by each panelist in the 2 sessions were averaged and used in the statistical analysis.

**Statistical Analysis**

Data were analyzed by the GLM of SAS (2000). The differences in the mean values were compared by Tukey’s multiple comparison ($P < 0.05$), and mean values and SEM were reported.

**RESULTS**

**Antimicrobials and Irradiation on the Survival and Growth of *L. monocytogenes***

The initial pH value of turkey breast rolls without antimicrobials was around 6.38 (Table 1), which is similar to commercial RTE turkey breast rolls (unpublished data). Adding SDA in formulation slightly lowered the pH value of products, but the difference was very small. Adding PB in formulation did not change the pH value of products. The pH of breast rolls of all treatments remained constant (change <0.03) during 42 d of storage (data not shown). The total plate counts for uninoculated samples at 0 d were beyond the detectable level in all 6 treatments (data not shown).

The survival curves of *L. monocytogenes* in RTE breast rolls with or without different antimicrobials following 0, 1.0, 1.5, 2.0, or 2.5 kGy irradiation were similar (Figure 1), indicating that antimicrobial additives did not increase the irradiation sensitivity of *L. monocytogenes* in RTE turkey rolls. The D$_{10}$ value for breast rolls with various additive treatments ranged from 0.56 to 0.58 kGy.

Figure 2 showed the growth of *L. monocytogenes* in nonirradiated vacuum-packaged RTE turkey rolls formulated with or without antimicrobial additives during storage at 4°C. In control turkey rolls without any preservatives, *L. monocytogenes* proliferated rapidly and reached peak number (8.2 log$_{10}$ cfu/cm$^2$) after 14 d of storage at 4°C. Adding PB (0.1%) or SL (2%) in turkey roll formulation failed to prevent *L. monocytogenes* from growing during refrigerated storage (Figure 2). In both PB and SL treatments, *L. monocytogenes* reached a peak number of 8.0 log after 21 d of refrigerated storage. Turkey rolls with 2 added antimicrobials showed a 14-d lag phase before *L. monocytogenes* growth (Figure 2). The PB + SL combination was less effective than the SL + SDA combination in inhibiting the growth of *L. monocytogenes* in turkey breast rolls. In the PB + SL treatment, *L. monocytogenes* reached a peak number of 7.8 log after 35 d of refrigerated storage and 42 d storage for the breast rolls treated with SL + SDA (Figure 2). Including the 3-antimicrobial (PB + SL + SDA) treatment was slightly more effective than 2-antimicro-
bial combinations in inhibiting the growth of *L. monocytogenes*. There was about a 21-d lag phase before *L. monocytogenes* started to grow (Figure 2).

The control turkey rolls irradiated at 1.0 or 2.0 kGy (Figure 3 and 4) had a 7-d lag phase. After the lag phase, the surviving bacterial pathogens started to proliferate in 1.0 and 2.0 kGy irradiated control turkey rolls, reaching peak after 21 and 35 d of refrigerated storage, respectively, indicating that low-dose irradiation itself could not provide safety margin for RTE turkey rolls. As showed in Figures 3 and 4, an extended lag phase was observed in turkey rolls formulated with antimicrobial and irradiated at 1.0 and 2.0 kGy, and stored at 4°C, especially for those turkey rolls with 2 or 3 combined antimicrobials. In turkey rolls with a single antimicrobial, 0.1% PB or 2% SL, there was a 14-d lag period after receiving 1.0 kGy irradiation, and then *L. monocytogenes* started to grow and reached 8 log_{10} cfu/cm^2.

Table 1. Formulation of oven-roast turkey breast rolls and pH in processed products

<table>
<thead>
<tr>
<th>Ingredient (%)</th>
<th>Control</th>
<th>PB</th>
<th>SL</th>
<th>PB + SL</th>
<th>SL + SDA</th>
<th>PSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meat</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Salt</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Phosphate (Brifisol)</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Transglutaminase</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Sodium caseinate</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Dextrose</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Water</td>
<td>6.25</td>
<td>6.25</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Potassium benzoate</td>
<td></td>
<td>0.1</td>
<td></td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Sodium lactate</td>
<td></td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Sodium diacetate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>pH Breast rolls</td>
<td>6.38</td>
<td>6.38</td>
<td>6.37</td>
<td>6.38</td>
<td>6.34</td>
<td>6.35</td>
</tr>
</tbody>
</table>

1Control = basic formula; PB = including 0.1% potassium benzoate; SL = including 2% sodium lactate; PB + SL = including 0.1% potassium benzoate and 2% sodium lactate; SL + SDA = including 2% sodium lactate and 0.1% sodium diacetate; PSS = including 0.1% potassium benzoate, 2% sodium lactate, and 0.1% sodium diacetate.

2B.K. Ladenburg Corp., Cresskill, NJ.

Figure 1. Survival of *Listeria monocytogenes* following irradiation in turkey rolls with or without antimicrobial additives (control = basic formula; PB = including 0.1% potassium benzoate; SL = including 2% sodium lactate; PB + SL = including 0.1% potassium benzoate and 2% sodium lactate; SL + SDA = including 2% sodium lactate and 0.1% sodium diacetate; PSS = including 0.1% potassium benzoate, 2% sodium lactate, and 0.1% sodium diacetate), n = 3.
cm² after 42 d of storage (Figure 3). In 2.0 kGy irradiated turkey rolls formulated with 2% SL or 0.1% PB, L. monocytogenes started to grow after a 21-d lag phase and reached 6 and 5 log₁₀ cfu/cm² at d 42, respectively (Figure 4), which is about the concentration before irradiation.

In turkey rolls formulated with 2 antimicrobials, PB + SL and SL + SDA, 1.0 kGy irradiation extended the lag phase to 21 and 28 d, respectively (Figure 3), and 2.0 kGy kept L. monocytogenes in lag phase throughout storage (Figure 4). Figure 3 showed that a dose of 1.0 kGy was effective in suppressing the growth of L. monocytogenes in turkey rolls with PB + SL or SL + SDA for about 6 wk when stored at 4°C. During 42-d refrigerated storage, 2.0 kGy irradiation was listeriostatic for turkey rolls with 2 antimicrobial combinations (Figure 4). In turkey rolls with 3 combined antimicrobials, PB + SL + SDA, and 1.0 or 2.0 kGy irradiation, L. monocytogenes stayed in the lag phase and no growth was observed after irradiation during the whole 42 d of refrigerated storage (Figure 3 and 4).

**Sensory Evaluation of Breast Rolls with Antimicrobials**

The data in this paper indicated that the addition of 2 or 3 antimicrobials in combination with 1.0 kGy irradiation could provide a safety margin for RTE turkey rolls during refrigerated storage. Therefore, turkey rolls formulated with basic formula, PB + SL, SL + SDA, and PB + SL + SDA, receiving 0 or 1.0 kGy irradiation were chosen for sensory analysis. Table 2 shows the effect of antimicrobials on the sensory characteristics of RTE turkey breasts receiving 1.0 kGy irradiation. According to the evaluation of the sensory panelists, 1.0 kGy irradiation has no significant effects on the sensory characteristics of RTE turkey breast (Table 2). Among turkey rolls without irradiation, turkey rolls formulated with SL + SDA had less turkey roll aroma and flavor and greater off-aroma and off-flavor than other treatments (Table 2), but for 1.0 kGy irradiated RTE turkey breast rolls, there was no significant difference in sensory characteristics between turkey rolls with SL + SDA and without.

**DISCUSSION**

In RTE turkey rolls, adding antimicrobials did not affect the irradiation sensitivity of L. monocytogenes, which is different from that of turkey hams and bologna. Including SDA in formulation increased irradiation sensitivity of cured products such as RTE turkey ham and bologna (Sommers et al., 2003; Zhu et al., 2005). The D₁₀ value obtained in this study was greater.
than the results from RTE turkey hams, in which the same \textit{L. monocytogenes} cocktail was inoculated and D$_{10}$ ranged from 0.48 to 0.52 kGy (Zhu et al., 2005). This difference could be related to the nitrite added in ham. These D$_{10}$ values were greater than that of commercial frankfurters, bologna, and turkey ham, which averaged about 0.44 kGy (Foong et al., 2004). The difference in D$_{10}$ value could be associated with the difference in formulation, \textit{L. monocytogenes} strains, the physiological state of the strain used, packaging condition, and plating medium (Patterson, 1989; Augustin, 1996; Tarte et al., 1996; Gürsel and Gürakan, 1997; Mendonca et al., 2004). In general, cells under stress showed greater levels of resistance to irradiation (Verma and Singh, 2001; Mendonca et al., 2004). Irradiation resulted in a lag phase of the growth of \textit{L. monocytogenes} in turkey rolls, which is consistent with former reports (Gürsel and Gürakan, 1997; Foong et al., 2004; Zhu et al., 2005). Addition of antimicrobials in turkey formulation greatly increased the lag phase at each irradiation dose, indicating that the injured bacterial cells need more time to repair irradiation-caused damage in the presence of antimicrobials.

Our results showed that including a single antimicrobial additive (2% SL or 0.1% PB) in turkey roll formulation was not sufficient to inhibit the proliferation of \textit{L. monocytogenes} surviving irradiation, which is consistent with previous results from turkey ham (Zhu et al., 2005) and other reports (Schlyter et al., 1993). In turkey slurries, Schlyter et al. (1993) found that 2.5% lactate failed to suppress the growth of \textit{L. monocytogenes} at 4°C. The anti-\textit{Listeria} activity of antimicrobial combination was well documented. Qvist et al. (1994) found that no growth occurred in samples formulated with 2% SL and 0.25% glucono-δ-lactone during 35 d of storage at 5 and 10°C (Qvist et al., 1994). A mixture of 2.5% lactate and 0.25% acetate inhibited the growth of \textit{L. monocytogenes} in turkey rolls for 5 wk at 4°C (Blom et al., 1997). On cured smoked wiener, adding ≥1% SL plus ≥0.1% SDA inhibited the growth of \textit{L. monocytogenes} for 60 d at 4.5°C (Glass et al., 2002). Turkey rolls without irradiation, however, 2% SL plus 0.1% SDA, or 2% SL plus 0.1% PB antimicrobials combination delayed the growth of \textit{L. monocytogenes} for about 2 wk and then pathogen organisms start to grow again at a lower growth rate than that in the control turkey rolls or turkey rolls formulated with a single antimicrobial. Including 3 antimicrobials in turkey roll formulation suppressed \textit{L. monocytogenes} from growth for about 21 d. Including 2 or 3 combinations of antimicrobials was very effective in control of the growth of \textit{L. monocytogenes} in turkey rolls receiving 1.0 or 2.0 kGy irradiation, and this was consistent with turkey hams (Zhu et al., 2005).

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure3}
\caption{Viability of \textit{Listeria monocytogenes} at 4°C in 1.0 kGy irradiated vacuum-packaged ready-to-eat turkey breast rolls with or without antimicrobial additives (control = basic formula; PB = including 0.1% potassium benzoate; SL = including 2% sodium lactate; PB + SL = including 0.1% potassium benzoate and 2% sodium lactate; SL + SDA = including 2% sodium lactate and 0.1% sodium diacetate; PSS = including 0.1% potassium benzoate, 2% sodium lactate, and 0.1% sodium diacetate), n = 3.}
\end{figure}
Sensory analysis indicated that turkey rolls formulated with SL + SDA had less turkey roll-like aroma and flavor than others, but no difference in turkey ham-like aroma and flavor was observed when they were added to turkey ham (Zhu et al., 2005). This could be related to the masking effect of intensive ham flavor and aroma.

Table 2. Sensory characteristics of ready-to-eat turkey breast rolls with or without antimicrobials, receiving 0 or 1.0 kGy irradiation1

<table>
<thead>
<tr>
<th>Irradiation</th>
<th>Control</th>
<th>PB + SL</th>
<th>SL + SDA</th>
<th>PSS</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkey rolls aroma 0 kGy</td>
<td>4.157ab</td>
<td>3.551ab</td>
<td>2.999b</td>
<td>5.261a</td>
<td>0.509</td>
</tr>
<tr>
<td>1.0 kGy</td>
<td>4.346</td>
<td>3.753</td>
<td>3.576</td>
<td>3.739</td>
<td>0.594</td>
</tr>
<tr>
<td>SEM</td>
<td>0.555</td>
<td>0.485</td>
<td>0.170</td>
<td>0.678</td>
<td></td>
</tr>
<tr>
<td>Off-aroma 0 kGy</td>
<td>4.064b</td>
<td>5.620ab</td>
<td>6.941a</td>
<td>4.140b</td>
<td>0.733</td>
</tr>
<tr>
<td>1.0 kGy</td>
<td>3.805</td>
<td>5.963</td>
<td>5.955</td>
<td>5.916</td>
<td>0.783</td>
</tr>
<tr>
<td>SEM</td>
<td>0.757</td>
<td>0.769</td>
<td>0.759</td>
<td>0.750</td>
<td></td>
</tr>
<tr>
<td>Turkey rolls flavor 0 kGy</td>
<td>5.027</td>
<td>4.170</td>
<td>3.605</td>
<td>5.572</td>
<td>0.622</td>
</tr>
<tr>
<td>1.0 kGy</td>
<td>5.085</td>
<td>3.809</td>
<td>3.585</td>
<td>3.952</td>
<td>0.505</td>
</tr>
<tr>
<td>SEM</td>
<td>0.566</td>
<td>0.473</td>
<td>0.531</td>
<td>0.677</td>
<td></td>
</tr>
<tr>
<td>Off-flavor 0 kGy</td>
<td>3.424b</td>
<td>4.975ab</td>
<td>6.450p</td>
<td>3.641b</td>
<td>0.753</td>
</tr>
<tr>
<td>1.0 kGy</td>
<td>3.855</td>
<td>5.183</td>
<td>5.707</td>
<td>5.368</td>
<td>0.777</td>
</tr>
<tr>
<td>SEM</td>
<td>0.778</td>
<td>0.753</td>
<td>0.852</td>
<td>0.717</td>
<td>0.800</td>
</tr>
<tr>
<td>Saltiness 0 kGy</td>
<td>5.215</td>
<td>6.648</td>
<td>7.346</td>
<td>7.398</td>
<td>0.744</td>
</tr>
<tr>
<td>1.0 kGy</td>
<td>5.642</td>
<td>7.803</td>
<td>7.350</td>
<td>7.001</td>
<td>0.635</td>
</tr>
<tr>
<td>SEM</td>
<td>0.669</td>
<td>0.739</td>
<td>0.692</td>
<td>0.663</td>
<td></td>
</tr>
</tbody>
</table>

Means within a row with no common letter differ significantly (P < 0.05).

1Control = basic formula; PB + SL = including 0.1% potassium benzoate and 2% sodium lactate; SL + SDA = including 2% sodium lactate and 0.1% sodium diacetate; PSS = including 0.1% potassium benzoate, 2% sodium lactate, and 0.1% sodium diacetate; n = 10.
This lower aroma and flavor could be associated with a lower pH in the SL + SDA turkey rolls. Williams and Phillips (1998) reported that the off-flavor caused by SL increased as the pH of meat decreased. One intriguing result is that SL + SDA in combination with PB had little effect on sensory characteristics. The reason could be due to the increased pH after adding PB. As shown in Table 1, there was a slight increase in pH for breast rolls containing PB + SL and SDA than that reported for SL + SDA. If this is the case, increasing phosphate content in the formulation for breast rolls containing SL + SDA could be a solution to avoid the side effects of SL + SDA on sensory characteristics, because phosphate can increase the pH of meat products. The RTE turkey breast rolls with PB + SL and PB + SL + SDA were acceptable as judged by sensory panelists.

From the microbiological safety point of view, both PB + SL and SL + SDA antimicrobial treatments in combination with 1.0 or 2.0 kGy irradiation were effective in controlling postpackaging contamination and proliferation of \textit{L. monocytogenes}, with SL + SDA more effective than PB + SL. Regarding sensory characteristics, PB + SL is better than SL + SDA in nonirradiated turkey rolls, but no significant difference was detected between turkey rolls with PB + SL and with SL + SDA that received 1.0 kGy irradiation. However, the volatile analysis indicated that the turkey rolls added with PB in formulation produced a significant amount of benzene during 1.0 or 2.0 kGy irradiation (Zhu et al., 2004b). Due to negative health effects of benzene during 1.0 or 2.0 kGy irradiation (Zhu et al., 2004b), PB + SL is better than SL + SDA in nonirradiated breast rolls containing PB + SL and SDA antimicrobial treatments in combination with 1.0 or 2.0 kGy irradiation were effective in controlling postpackaging contamination and proliferation of \textit{L. monocytogenes} important to food processors. Pages 134–224 in \textit{Listeria}, listeriosis and food safety. E. T. Ryser and E. H. Marti, ed. Marcel Dekker Inc., New York, NY.


ACKNOWLEDGMENTS

The research was supported by the Midwest Poultry Consortium.

REFERENCES


