Control of *Salmonella enterica* Typhimurium in Chicken Breast Meat by Irradiation Combined with Modified Atmosphere Packaging

L. L. KUDRA,1,2 J. G. SEBRANEK,1,2* J. S. DICKSON,1,2 A. F. MENDONÇA,2 Q. ZHANG,3 A. JACKSON-DAVIS,3 AND K. J. PRUSA2

1Department of Animal Science, 2Department of Food Science and Human Nutrition, and 3Department of Veterinary Microbiology and Preventing Medicine, Iowa State University, Ames, Iowa 50011, USA

ABSTRACT

*Salmonella* is one of the leading causes of human foodborne illnesses originating from meat and poultry products. Cross-contamination of *Salmonella* from raw to cooked products continues to be problematic in the food industry. Therefore, new intervention strategies are needed for meat and poultry products. Vacuum or modified atmosphere packaging (MAP) are common packaging techniques used to extend the shelf life of meat products. Irradiation has been well established as an antibacterial treatment to reduce pathogens on meat and poultry. Combining irradiation with high-CO2 + CO MAP was investigated in this study for improving the control of *Salmonella enterica* Typhimurium on chicken breast meat. The radiation sensitivities (*D*10-values) of this pathogen in chicken breast meat were found to be similar in vacuum and in high-CO2 + CO MAP (0.55 ± 0.03 kGy and 0.54 ± 0.03 kGy, respectively). Irradiation at 1.5 kGy reduced the *Salmonella* population by an average of 3 log. Some *Salmonella* cells survived in both vacuum and high-CO2 + CO MAP through 6 weeks of refrigerated storage following irradiation. This pathogen also grew in both vacuum and MAP when the product was held at 25 °C. This study demonstrated that irradiation is an effective means of reducing *Salmonella* on meat or poultry, but packaging in either vacuum or MAP had little impact during subsequent refrigerated storage.

Many studies have shown that *Salmonella enterica* is the most common cause of foodborne illnesses in the world (24). Nevertheless, surveillance based on consumer complaints is extremely difficult to assess (19). In addition, the number of strains that are resistant to one or more drugs continues to increase (20). The human gastroenteritis caused by this pathogen has been frequently associated with the handling or consumption of contaminated poultry products (24). The poultry industry has spent a considerable amount of time and resources in an effort to control the incidences of *Salmonella* in live birds and to eliminate the contamination or cross-contamination of this bacterium on poultry carcasses (23). Common practices for control on farms include the application of antimicrobials in feed or water along with environmental hygiene. In processing plants, postharvest scalding sprays and carcass chilling with chlorinated water are used as intervention strategies along with the hazard analysis and critical control point system (21, 23). While the current interventions have significantly reduced consumer exposure to this food hazard, the industry has faced persistent or even increased frequency of positive samples of *Salmonella* among broilers as shown by U.S. Department of Agriculture Food Safety and Inspection Service testing (2, 29). The rising prevalence of *Salmonella* suggests that current methods used to reduce the contamination or cross-contamination of *Salmonella* on broilers are not fully effective. Therefore, additional control measures are needed to further reduce the prevalence of this pathogen on poultry products (13, 42).

The use of ionizing radiation to inactivate *Salmonella* and other foodborne pathogens in meat and poultry products has been well documented (18). However, irradiation has been reported to cause meat quality changes, such as off-odor, changes in meat color, and lipid oxidation (27, 28). These adverse quality effects have also been documented in nonmeat products (31) and have contributed to the limited consumer acceptance of commercialized irradiated fresh meat products (26). To minimize the negative quality effects of irradiation in fresh meat products, many studies have been conducted on the potential combination of other hurdle technologies with irradiation to reduce the radiation dose needed and still maintain both the safety and quality of irradiated meat products. One of the approaches suggested has been the combination of irradiation with modified atmosphere packaging (MAP) (17).

MAP with carbon dioxide at either low (20 to 30%) or high (60 to 100%) concentration has been shown in many studies to inhibit spoilage bacteria and to extend the shelf life of fresh meat and poultry (15, 32, 38). It was also
observed that high-CO₂ MAP inhibited the growth of Escherichia coli O157:H7, Salmonella, Listeria monocytogenes, and Campylobacter jejuni in meat products (12, 32). Some studies have combined irradiation with MAP to control foodborne pathogens in the meat products. Patterson (30) reported that Salmonella Typhimurium and E. coli O157:H7 in minced chicken meat were more sensitive to irradiation in MAP with 100% CO₂ than in air. However, Chiasson et al. (6) observed that when ground beef was packaged in MAP with 30% CO₂, 60% O₂, and 10% N₂, E. coli O157:H7 and Salmonella Typhimurium were more sensitive to irradiation than in MAP containing 100% CO₂ or in vacuum packages. In an effort to avoid lipid oxidation induced by irradiation, packaging techniques that eliminate oxygen from meat or poultry products are preferred (1). Therefore, when combined with irradiation, high-CO₂ (low-O₂) MAP might be a feasible approach to control Salmonella in poultry products while minimizing quality changes. However, a high concentration of CO₂ in MAP can cause undesirable color change in meat and poultry products (5, 15). Further, if MAP contains a small amount of residual oxygen, fresh meat color will deteriorate at a faster rate than in aerobic packaging during storage (41).

While CO₂ has been used for MAP of meat and poultry for many years, the U.S. Food and Drug Administration has only recently approved carbon monoxide (0.4%) as a MAP gas (40). Carbon monoxide reacts with meat myoglobin to produce bright cherry-red carboxymyoglobin pigment with greater oxidative and color stability than oxymyoglobin (22). Therefore, the addition of CO into high-CO₂ MAP has potential to minimize the color deterioration in fresh meat and poultry caused by a high concentration of CO₂ in MAP and to reduce the adverse color effects of irradiation pasteurization. Nevertheless, few studies have investigated the recovery or survival of Salmonella on irradiated meat products in high-CO₂ + CO packaging at refrigeration (4°C) or in a temperature abuse environment (25°C).

The objective of this study was to test the hypothesis that irradiation combined with high-CO₂ + CO MAP is at least as effective as irradiation with vacuum packaging for reducing S. enterica Typhimurium on fresh chicken breast meat and would be more effective than vacuum packaging for inhibiting the growth of survivors during refrigerated storage period at 4°C or after exposure to 25°C. To test this hypothesis, vacuum packaging and high-CO₂ MAP were used for inoculated chicken breasts following irradiation at 0, 0.5, and 1.5 kGy.

**MATERIALS AND METHODS**

**Preparation of bacterial cultures.** Four strains of S. enterica Typhimurium (S-07, S-G25, S-G26, and S-G27) were selected from the culture bank of the Food Safety Research Laboratory (FSRL) in the Iowa State University Department of Animal Science as a general cross section of Salmonella. The strains are not associated with outbreaks. G7 is a serovar Enteritidis isolated from the environment. G25, G26, and G27 are of the serovar Typhimurium. G25 is of an unknown origin. G26 and G27 were isolates of poultry. Frozen stocks were separately transferred to 10 ml of tryptic soy broth (TSB; Difco, BD, Sparks, MD) and incubated at 37°C for 24 h. The cultures were streaked onto tryptic soy agar (Difco, BD) slants and incubated at 37°C for 24 h. The slants were stored under refrigeration at the Iowa State University FSRL and used as stock for the three replications of the study. A loopful of each Salmonella culture was transferred into 10 ml of TSB and incubated at 37°C for 24 h. One milliliter of the broth culture was then individually transferred into 99 ml of TSB and incubated at 37°C for 24 h. The level of the bacteria reached approximately 8 log/ml. The inoculum was prepared by combining 2.5 ml of each culture into 90 ml of peptone water. The cocktail contained approximately equal numbers of each strain with a total level of 7 log/ml.

**Preparation of meat samples.** Refrigerated fresh, skinless chicken breasts (packaged on foam trays, three or four pieces per tray) were purchased from a local supplier. Individual chicken breasts were weighed and trimmed to about 100 g each. Single pieces of chicken breast were placed into high-barrier pouches (Curlon Grade 861, 3 cm³ of O₂/645 cm²/24 h at 23°C and 0% relative humidity; Cryovac Packaging, Duncan, SC). The packaging film provided for essentially no transmission of CO₂ or CO, though specific permeability data for these gases were not available. The chicken breasts were immediately transferred to the FSRL for inoculation.

**Inoculation and packaging.** One milliliter of inoculum was placed on the chicken breast in each pouch with a sterilized pipette. The packages were manually massaged for about 1 to 2 min to distribute the inoculum evenly. The level of Salmonella on each piece of chicken breast meat was approximately 5 log/g. Pouches were immediately vacuum or MAP packaged with a Multivac Packaging Machine (model A 300/52, Multivac Inc., Wolfertschwenden, Germany) in the FSRL. Cylinders with the desired gas mixture (99.5% CO₂ and 0.5% CO) for MAP were purchased (Linweld Co., Lincoln, NE). After vacuum was applied (10 to 13 mbar [1 to 1.3 kPa]), the gas mixture was flushed into the pouches (gas pressure of 680 to 700 bar [68 × 10³ to 70 × 10³ kPa]) with simultaneous sealing. The volume ratio of gas to the chicken breast meat in a single MAP package was about 4:1. After inoculation and packaging, samples were stored at 4°C for 12 h before irradiation.

**Irradiation of chicken breast meat.** The inoculated, packaged samples were irradiated at the Iowa State University Linear Accelerator Facility. The electron beam irradiation was generated by a Circe-III linear electron accelerator at an energy level of 10 MeV and 10 kW (MeV Industries S.A., Jouy-en-Josas, France). The target irradiation doses for chicken breast meat containing Salmonella were 0.5, 1.0, and 1.5 kGy. Alamine pellet dosimeters (5 by 5 mm; Broker Analytische Messtechnik, Rheinstetten, Germany) were placed on the top and bottom surfaces of sample pouches to measure the actual absorbed energy (dose). Immediately after irradiation, the absorbed doses were measured by electron paramagnetic resonance on a Broker EMS 104 EPR Analyzer. The average surface dose, overall average dose, and average maximum doses absorbed by the chicken breast meat in vacuum and MAP are listed in Table 1. The average surface dose was the calculated average of the doses recorded by dosimeters at two locations on the surface of the samples. The average maximum dose was measured on the bottom of the samples where the maximum electron beam penetration occurred and was again an average of doses measured by dosimeters at two locations on the bottom side of the samples. The overall average dose is the calculated mean of the surface and maximum doses. Following irradiation, the samples were stored at 4°C in the FSRL.
Microbiological analysis. Samples were plated immediately after irradiation. The packages of chicken breast meat were opened aseptically, and the meat was cut into small pieces with sterilized scissors. Packages were then massaged manually. Twenty-five grams of sample from each package was aseptically weighed into a sterile plastic stomacher bag (Whirl-Pak filter bag B01318, Nasco, Ft. Atkinson, WI) with 225 ml of peptone water (Difco, BD) and homogenized in a stomacher blender (Seward Stomacher Blender, model 4000, Tekmar Co., Cincinnati, OH) for 60 s at high speed. Aliquots (0.1 ml) of the homogenate were surface plated onto xylose lysine deoxycholate (Difco, BD) plates. The plates were incubated at 37°C for 24 h.

Determination of $D_{10}$-value. Radiation $D_{10}$-value of bacteria is defined as the amount of radiation energy (dose) needed to reduce 90% (CFU) of the target microorganism in irradiated food products. The $D_{10}$-value was determined by calculating the negative reciprocal of the slope of the regression line for the plot of the number of survivors (in log CFU per gram) versus irradiation dose (in kilograys) (14).

Enumeration of survivors during storage. Recovery of the pathogen on irradiated chicken breast meat was measured after 24 and 48 h of storage at 4°C and at 1-week intervals for 6 weeks to determine the fate of the survivors. For the temperature abuse test, samples were held for 7 days at 4°C followed by room temperature (25°C) for 48 h prior to enumeration. The plating method was the same as for the determination of $D_{10}$-values.

Statistical analysis. A general linear model (SPSS 14.0 Window Grad Pack) was used to evaluate the effects of irradiation dose, packaging types, and storage time. When there were significant effects or interactions ($P < 0.05$) between experimental factors, the linear contrast test, the independent sample $t$ test, or post hoc tests of differences with Tukey adjustment were used to analysis the significance of main and simple main effects, or simple-simple main effects. A random block design was used for the experiment. A $2 \times 4$ factorial design was used to determine radiation $D_{10}$-values for $S. enterica$ Typhimurium in chicken breast meat and to assess the survivor growth status during refrigerated storage and under the temperature abuse conditions. Three samples were measured for each treatment in the experiment. Three independent replications were performed.

RESULTS AND DISCUSSION

Radiation $D_{10}$-value. Table 2 lists the radiation $D_{10}$-values of $S. enterica$ Typhimurium on chicken breast meat irradiated in vacuum and in high-CO$_2$ + CO MAP packages. The $D_{10}$-values in vacuum packaging and MAP were 0.55 ± 0.03 kGy and 0.54 ± 0.03 kGy, respectively. The packaging techniques (vacuum or MAP) did not affect the $D_{10}$-value of this pathogen ($P = 0.775$). Forshall and Wierup (13) reported that the radiation sensitivities of Salmonella Typhimurium in ground beef were similar in vacuum and in 100% CO$_2$ MAP packages, although the reported $D_{10}$-values (0.43 ± 0.01 kGy in vacuum and 0.42 ± 0.00 kGy in 100% CO$_2$ MAP) in that study were less than those observed in the present study. Those authors also reported that Salmonella Typhimurium in ground beef was more sensitive to irradiation when packaged in vacuum or 100% CO$_2$ MAP than when packaged aerobically. However, in a previous study by Chiasson et al. (7), Salmonella Typhimurium on ground beef showed greater sensitivity to irradiation in MAP containing oxygen (60% O$_2$–30% CO$_2$–10% N$_2$) than in vacuum packaging. Patterson (30) reported that Salmonella Typhimurium in minced chicken meat was equally sensitive to irradiation in 100% CO$_2$ MAP and in air (0.442 and 0.436 kGy, respectively). Thayer and Boyd (36) reported that Salmonella Typhimurium ATCC 14028 (inoculated in mechanically deboned chicken meat or on the surface of chicken legs) had the same radiation sensitivity in vacuum and in air when the products were treated at the same temperature. Increasing the temperature increased the lethal effect of irradiation on this bacterium. However, in a separate study, Thayer and Boyd (37) also observed that if sterilized mechanically deboned meat was inoculated with Salmonella Typhimurium (without background microflora), this pathogen was more sensitive to irradiation in air than in vacuum. Many other studies have shown that the radiation sensitivity observed for Salmonella was dependent on the type of meat product (35), the product temperature (8), the physiological state of the bacteria (4), and the inherent radiation resistance of different serovars (33).

The reduction in number of Salmonella organisms resulting from the irradiation treatment at 1.5 kGy was 2.95 to 3.21 log following the treatment (Tables 3 and 4). The treatment with 0.5 kGy achieved a reduction of 0.78 to 1.07 log initially, while the 1.0-kGy dose reduced Salmonella by 1.59 to 2.04 log with no significant differences between packaging treatments or for refrigerated storage time for any of the different irradiation treatments.

Recovery of Salmonella. There were no packaging or time effects on the recovery of Salmonella Typhimurium at 4°C for 24 or 48 h ($P = 0.454$ for the packaging effect and 0.159 for the time effect; other analysis of variance results not shown). Salmonella in irradiated or nonirradiated chicken breast meat packaged in vacuum packaging or MAP showed no significant growth in any of samples at 4°C within 24 or 48 h (data not shown). The initial reduction of about 3 log in the number of Salmonella cells, as noted earlier, was sustained during refrigerated storage in both packaging treatments. Therefore, irradiation was...
<table>
<thead>
<tr>
<th>Target irradiation dose (kGy)</th>
<th>Mean (log CFU/g)</th>
<th>SEM</th>
<th>Mean (log CFU/g)</th>
<th>SEM</th>
<th>Mean (log CFU/g)</th>
<th>SEM</th>
<th>Mean (log CFU/g)</th>
<th>SEM</th>
<th>Mean (log CFU/g)</th>
<th>SEM</th>
<th>Mean (log CFU/g)</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.02</td>
<td>0.17</td>
<td>6.39</td>
<td>1.00</td>
<td>5.46</td>
<td>0.22</td>
<td>5.24</td>
<td>0.13</td>
<td>5.23</td>
<td>0.08</td>
<td>5.03</td>
<td>0.16</td>
</tr>
<tr>
<td>0.5</td>
<td>3.95 ABC</td>
<td>0.28</td>
<td>4.53 B</td>
<td>0.12</td>
<td>4.44 AB</td>
<td>0.27</td>
<td>3.13 C</td>
<td>0.22</td>
<td>3.83 ABC</td>
<td>0.32</td>
<td>3.31 C</td>
<td>0.12</td>
</tr>
<tr>
<td>1.0</td>
<td>2.98</td>
<td>0.44</td>
<td>3.08</td>
<td>0.25</td>
<td>2.86</td>
<td>0.16</td>
<td>2.40</td>
<td>0.24</td>
<td>2.28</td>
<td>0.30</td>
<td>2.59</td>
<td>0.22</td>
</tr>
<tr>
<td>1.5</td>
<td>1.81 A</td>
<td>0.25</td>
<td>1.74 A</td>
<td>0.19</td>
<td>1.25 AB</td>
<td>0.57</td>
<td>1.10 AB</td>
<td>0.10</td>
<td>1.08 AB</td>
<td>0.39</td>
<td>0.16 B</td>
<td>0.16</td>
</tr>
</tbody>
</table>

*Mean values within the same row followed by different letters are significantly different (P < 0.05).*

---

<table>
<thead>
<tr>
<th>Target irradiation dose (kGy)</th>
<th>Mean (log CFU/g)</th>
<th>SEM</th>
<th>Mean (log CFU/g)</th>
<th>SEM</th>
<th>Mean (log CFU/g)</th>
<th>SEM</th>
<th>Mean (log CFU/g)</th>
<th>SEM</th>
<th>Mean (log CFU/g)</th>
<th>SEM</th>
<th>Mean (log CFU/g)</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.75</td>
<td>0.24</td>
<td>5.22</td>
<td>0.13</td>
<td>5.34</td>
<td>0.08</td>
<td>5.18</td>
<td>0.24</td>
<td>5.23</td>
<td>0.23</td>
<td>5.52</td>
<td>0.10</td>
</tr>
<tr>
<td>0.5</td>
<td>3.97 AB</td>
<td>0.27</td>
<td>3.91 AB</td>
<td>0.16</td>
<td>4.25 A</td>
<td>0.18</td>
<td>3.21 B</td>
<td>0.20</td>
<td>4.53 A</td>
<td>0.18</td>
<td>3.28 C</td>
<td>0.07</td>
</tr>
<tr>
<td>1.0</td>
<td>3.16</td>
<td>0.08</td>
<td>3.19</td>
<td>0.15</td>
<td>2.80</td>
<td>0.24</td>
<td>2.76</td>
<td>0.14</td>
<td>2.68</td>
<td>0.10</td>
<td>3.05</td>
<td>0.27</td>
</tr>
<tr>
<td>1.5</td>
<td>1.80</td>
<td>0.21</td>
<td>2.30</td>
<td>0.09</td>
<td>2.42</td>
<td>0.12</td>
<td>1.77</td>
<td>0.46</td>
<td>1.98</td>
<td>0.32</td>
<td>2.00</td>
<td>0.25</td>
</tr>
</tbody>
</table>

*Mean values within the same row followed by different letters are significantly different (P < 0.05).*
effective for reducing Salmonella on chicken breast meat, regardless of vacuum or high-CO₂+CO MAP. Consequently, if these packaging techniques are applied for the shelf life extension of poultry products, irradiation is a feasible means for improving the control of the pathogen in either case. It is important to note that the experiment was conducted with commercial meat samples. In an effort to mimic contamination as it would typically occur, samples were not sterilized before inoculation. Consequently, selective agar was used to allow growth of Salmonella while limiting growth of competitive bacteria. This may also have limited the recovery of injured Salmonella cells. Because Salmonella is a mesophilic microorganism, the minimum growth temperature for Salmonella Typhimurium is 6.2°C (16). Therefore, no growth at refrigeration temperature was expected. Szczawinska et al. (34) reported that there was no growth of several S. enterica serotypes observed on vacuum-packaged mechanically deboned chicken meat when the product was stored at 5°C for 9 days. Dykes and Moorhead (10) reported that serotypes of S. enterica inoculated on primal beef cuts did not grow in vacuum packaging or 100% CO₂ MAP during 2 weeks of storage at 4°C. Dickson and Olson (9) reported that no significant growth of S. enterica serotypes in irradiated or nonirradiated ground beef was observed at 4°C.

**Survival of Salmonella during refrigerated storage.** There was no significant effect of storage or packaging on the survival of Salmonella in irradiated or nonirradiated chicken breast meat during refrigerated storage for 6 weeks (P = 0.140 for the storage effect and 0.712 for the packaging effect; analysis of variance results not shown). However, this bacterium was observed to remain viable during storage at refrigerated temperature. Overall results (Tables 3 and 4) illustrate that there was no significant growth or reduction of Salmonella in irradiated or nonirradiated chicken breast meat packaged in vacuum or MAP during the refrigerated storage, regardless of the irradiation dose. Salmonella in chicken breast meat packaged in vacuum showed slight changes in some of the samples, such as in 1.0- or 1.5-kGy treatments in vacuum packages. However, these changes were not consistent in the three replications, and the variation in counts at the different time points was large enough that statistical significance could not be shown. Therefore, these observed differences were most likely caused by variation in the enumeration procedures. The survival patterns for Salmonella were similar in vacuum and in high-CO₂+CO MAP packages, and the survivors were viable in most of the packages for 6 weeks of refrigerated storage. Although growth at refrigeration temperature (2 to 4°C) is not physiologically feasible for Salmonella, many other studies have also shown that this pathogen has the ability to survive on meat and poultry products through refrigerated storage (3, 32). In the model developed by Ekland and Jarmund (11), Salmonella Typhimurium did not grow but survived in air, vacuum, or CO₂ packaging during 23 days of storage at 2 or 6°C.

**Growth of Salmonella during temperature abuse conditions.** After 1 week of postirradiation storage at 2 to 4°C, portions of the chicken breast samples were exposed to room temperature (25°C) for 48 h. There was a significant temperature effect (P = 0.017) and irradiation dose effect (P = 0.012) on the growth of Salmonella in irradiated or nonirradiated chicken breast meat under these conditions, irrespective of packaging type (P = 0.141). There was also interaction between the temperature and packaging (analysis of variance results not shown). The data in Table 5 show that the population of Salmonella Typhimurium in chicken breast meat increased significantly during temperature abuse. The cell count increased by an average of 3 log in all samples regardless of the irradiation dose or the packaging environment.

**Table 5. Growth of Salmonella Typhimurium on irradiated chicken breast meat at 25°C for 48 h**

<table>
<thead>
<tr>
<th>Target irradiation dose (kGy)</th>
<th>Count (log CFU/g) in vacuum packages</th>
<th></th>
<th>Count (log CFU/g) in MAP packages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (4°C) SEM</td>
<td>Mean (25°C) SEM</td>
<td>Mean (4°C) SEM</td>
</tr>
<tr>
<td>0.0</td>
<td>5.52 AX 0.34</td>
<td>8.04 BY 0.13</td>
<td>4.96 AX 0.13</td>
</tr>
<tr>
<td>0.5</td>
<td>4.45 CX 0.32</td>
<td>7.31 BY 0.36</td>
<td>4.18 AX 0.15</td>
</tr>
<tr>
<td>1.0</td>
<td>2.73 DX 0.18</td>
<td>7.21 BY 0.14</td>
<td>2.97 CX 0.08</td>
</tr>
<tr>
<td>1.5</td>
<td>1.71 EX 0.27</td>
<td>6.46 BY 0.08</td>
<td>1.84 DX 0.22</td>
</tr>
</tbody>
</table>

*Mean values of the same packaging type within the same row followed by different letters (x and y) are significantly different (P < 0.05). Mean values of the same packaging type within the same column followed by different letters (α through ε) are significantly different (P < 0.05).*
Jarmund (11), the effect of 100% CO₂ in MAP on the growth of Salmonella Typhimurium at 25°C was obvious in comparison with air, vacuum, or 100% N₂ MAP packaging during the first 5 days of incubation. However, after 14 and 23 days of incubation, the population of Salmonella in the CO₂ MAP exceeded the population in vacuum packages. Gill and DeLacy (14) observed that CO₂ MAP was significantly more effective than vacuum packaging for control of the growth of Salmonella Typhimurium on beef (pH 6.0) when the product was stored at 8 to 12°C. However, when the storage temperature was raised to 15°C, CO₂ lost its bacteriostatic function. Michaelson et al. (25) reported similar observations in their study on control of Salmonella on pork chops with high-CO₂ MAP. In the Michaelson study, Salmonella Typhimurium did not grow at 10°C for 35 days in high-CO₂ MAP, but growth was observed in vacuum packages after 7 days of storage at the same temperature.

Irradiation was effective for reducing Salmonella Typhimurium in fresh chicken breast meat, as expected. With a dose of 1.5 kGy, irradiation reduced Salmonella populations by an average of 3 log in chicken breasts, regardless of vacuum packaging or high-CO₂ MAP. Results from the microbiological assessments in this study indicated that high-CO₂+CO MAP did not demonstrate any advantage over vacuum packaging for improved control of Salmonella Typhimurium. The survivors of this foodborne pathogen did not grow but continued to persist in vacuum packaging or high-CO₂+CO MAP through 6 weeks of refrigerated storage. Further, Salmonella counts increased on chicken breasts when the product was exposed to 25°C for 48 h, regardless of the packaging treatment. Therefore, if the initial contamination of these pathogens is high, cross-contamination of ready-to-eat food or temperature abuse of the product is likely to continue to be a food safety concern, regardless of irradiation treatment doses or packaging treatments, at least within the range of those variables evaluated in this study.

ACKNOWLEDGMENT

This research was supported by the U.S. Department of Agriculture Cooperative State Research, Education, and Extension Service (National Integrated Food Safety Initiative), Grant No. 2003-51110-02077.

REFERENCES