Effects of Acid Adaptation and Modified Marinades on Survival of Postdrying *Salmonella* Contamination on Beef Jerky during Storage

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ABSTRACT

This study was undertaken to evaluate the survival of acid-adapted and nonadapted *Salmonella* cultures inoculated after drying on beef jerky that had been treated with marinades before drying at 60°C for 10 h. Beef slices were (i) not treated prior to refrigeration at 4°C for 24 h (control [C]); (ii) marinated with traditional marinade (TM), (iii) marinated with TM modified with 1.2% sodium lactate, 9% acetic acid, and 68% soy sauce containing 5% ethanol (MM) at twice the amount used in the TM treatment; (iv) dipped into 5% acetic acid and then marinated with TM (AATM); and (v) dipped into 1% Tween 20, then dipped into 5% acetic acid, and then marinated with TM (TWTM); after each treatment, meat slices were refrigerated at 4°C for 24 h prior to drying. Dried slices were inoculated with acid-adapted or nonadapted *Salmonella* (ca. 5.7 log CFU/cm²) prior to aerobic storage at 25°C for 60 days. Tryptic soy agar with 0.1% pyruvate, as well as xylose-lysine-tergitol 4 (XLT4) agar, was used to determine survivor counts. Bacterial decreases achieved with the different treatments were found to be in the following order: TWTM (5.4 to 6.3 log units) ≥ AATM ≥ MM ≥ C ≥ TM (2.9 to 5.1 log units). Acid-adapted *Salmonella* decreased faster than nonadapted *Salmonella* for all treatments. Bacterial populations decreased to below the detection limit (2.0 log CFU/cm²) in as few as 14 days or remained detectable by direct plating after 60 days of storage, depending on acid adaptation, treatment, and agar media. The results of this study indicate that the modified marinades used in jerky processing and the low water activity of the dried product provide antimicrobial effects against possible postprocessing contamination with *Salmonella*, while the preparation of cultures under acid-adaptation conditions did not increase *Salmonella* survival during storage and may have reduced it.

Eidson et al. (7) reviewed eight foodborne outbreaks (occurring from 1966 to 1995) associated with the consumption of contaminated whole-muscle beef jerky with *Salmonella* (six outbreaks) and *Staphylococcus aureus* (two outbreaks) in New Mexico. These authors concluded that process failures of various types (e.g., improper drying, no preservatives) were a major problem, although the possibility of postprocessing contamination could not be excluded. A recent report (18) by the Food Safety and Inspection Service of the U.S. Department of Agriculture indicated that from 1990 to 1999, the cumulative prevalence of *Salmonella* in jerky produced in federally inspected plants in the United States was 0.31%. These data, combined with documented outbreaks (6, 16) associated with jerky consumption, have increased concerns about the microbiological safety of beef jerky, which is one of the oldest forms of preserved meat products. Studies have been conducted to investigate the effectiveness of various predrying treatments and drying parameters (time, temperature) of the jerky-making process in inactivating *Salmonella* and other pathogens (1, 10–13, 16). However, to our knowledge, the survival of pathogens, including *Salmonella*, on jerky products inoculated after drying has not been studied. Data on the behavior of *Salmonella* on dry foods during storage are also limited (15, 17). The extent and duration of the survival of pathogenic bacteria on jerky during storage may be affected by the history of the bacteria (e.g., the history of such bacteria may impart stress resistance such as acid adaptation), by product composition, and by environmental factors or hurdles. The application of new intervention technologies designed on the basis of an understanding of bacterial survival strategies (e.g., mechanisms of survival or stress resistance) in food-processing procedures may improve the microbial safety of our food supply. Therefore, in this study, acid-adapted and nonadapted *Salmonella* were inoculated on whole-muscle beef jerky after drying to simulate postdrying contamination, and the objective of the study was to investigate the survival of the *Salmonella* during storage at ambient temperature.

MATERIALS AND METHODS

Inoculum. A five-strain composite inoculum of *Salmonella Typhimurium* was used to inoculate beef slices. The strains included in the inoculum were SF530 (UK1), R-4 (Copenhagen, DT104), R-5 (Copenhagen, DT104), ATCC 700408, and ATCC 14028. Each strain was propagated (35°C, 24 h) and maintained on tryptic soy agar (Difco Laboratories, Sparks, Md.) slants at 4°C. Strains were subcultured monthly. The cultures were activated by transferring a loopful of each strain into 9 ml of tryptic...
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soy broth (TSB; Difco) and incubating the broth at 35°C for 24 h. A 0.1-ml portion of each culture was then transferred into 9-
ml tubes of glucose-free TSB for non-acid-adapted cells and into 9-
ml tubes of glucose-free TSB with 1% added glucose for acid-
adapted cells (25). After incubation at 35°C for 22 to 24 h, indi-
vidual cultures were combined in a sterile tube prior to centrifu-
gation at 6,000 rpm (2,900 × g) for 15 min at 21°C. It should be
noted that the pH values of the supernatants were 4.9 and 7.1 for
acid-adapted and nonadapted cultures, respectively. According to
previous studies conducted by us (unpublished) and by others
(25), these pH values are indicative of the generation of acid-
adapted cultures in glucose-enriched broth. The resulting pellet
was washed once with 0.1% phosphate-buffered saline (PBS; Sig-
ma, St. Louis, Mo.) to remove residual organic material, recent-
trifuged, and then resuspended in PBS to a final volume of 50 ml.
The average inoculum concentration was 8.2 log CFU/ml.

Jerky processing. Vacuum-packaged, frozen (at −18°C for
< 3 weeks) beef slices (0.6 by 8.7 by 4.0 cm) were thawed at 4°C
overnight and then subjected to the following predrying treat-
ments: (i) no treatment (control [C]), (ii) marination with tradi-
tional marinade (TM, pH 4.3), (iii) marination with modified mar-
inade (MM, pH 3.0) at twice the amount used in the TM treat-
ment, (iv) dipping into 5% acetic acid solution (pH 2.5) for 10
min followed by marination in TM (AATM), and (v) sequential
dipping into 1% Tween 20 solution (polyoxyethylene-20-sorbitan
monolaurate, pH 6.6) for 15 min and then into 5% acetic acid
solution for 10 min followed by marination with TM (TWTM).
The traditional marinade used in the TM, AATM, and TWTM
treatments was selected from a commonly used food preservation
book (2) and consisted of 60 ml of soy sauce (Kikkoman Foods,
Walworth, Wis.), 15 ml of Worcestershire sauce (Heinz, Pitts-
burgh, Pa.), 0.6 g of black pepper (Heller Seasoning and Ingre-
dients Inc., Chicago, Ill.), 1.25 g of garlic powder (Excelsior Sea-
soning Co. Ltd., Pekin, Ill.), 1.5 g of onion powder (Excelsibir),
and 4.35 g of old hickory smoked salt (Tone Brothers Inc., An-
keny, Iowa) per kg of meat slices marinated (65 slices of 15 g
each). The modified marinade used in the MM treatment was pre-
pared for 1.0 kg of meat as follows: 120 ml of “milder soy sauce”
(Kikkoman) containing approximately 4.7 to 5.0% ethanol as a
preservative, 30 ml of Worcestershire sauce, 0.6 g of black pepper,
1.25 g of garlic powder, 1.5 g of onion powder, 4.35 g of smoke-
flavored salt, 3.6 ml of food-grade sodium-l-lactate (60% prepa-
ration; Purac Inc., Lincolnshire, Ill.), and 16 ml of glacial acetic
acid (Mallinckrodt Baker Inc., Paris, Ky.) to adjust the pH to 3.0.
The TM and MM products were prepared by a similar process.
With heat-sterilized forceps, beef slices were dipped manually into
the appropriate marinade and then placed on an aluminum-covered
tray. When all slices had been dipped and placed on trays, any
remaining marinade was evenly spread over the slices, and the
slices were manually mixed with sterilized forceps to ensure uni-
form marinade coverage. For the AATM treatment, meat slices
were dipped into 5% (vol/vol) acetic acid solution prepared with
glacial acetic acid (1.0 liters/kg) at ambient temperature for 10
min. These slices were then placed on a dehydrator tray with an
aluminum foil–covered tray underneath to drain excess fluid for
2 min, and they were then marinated with traditional marinade
as described for the TM treatment. For the TWTM treatment, meat
slices were first dipped into 1% (vol/vol) Tween 20 (Fisher Sci-
entific Inc., Fair Lawn, N.J.) solution (1.0 liters/kg) for 15 min at
ambient temperature. After these slices were drained for 2 min,
steps for the AATM treatment were followed. The black pepper,
garlic, and onion powders used had been irradiated by their man-
ufacturers. After the treatments, the slices on the trays were cov-
ered with aluminum foil and held at 4°C for 24 h prior to drying.

After refrigeration for 24 h, the treated meat slices were dried
at 60°C for 10 h in American Harvest Gardenmaster dehydrators
(Model FD-1000, Nesco, Chaska, Minn.). The dehydrator air
temperature was measured with thermocouples (Type K beaded
probes, Pico Technology Ltd., Cambridge, UK) inserted through
the middle opening of the dehydrator. Although the temperature
of the meat slices was not measured in this study, results of other
unpublished experiments from our laboratory have shown that the
temperature of meat slices is close to the air temperature (ap-
proximately 60°C) after 4 to 5 h of drying. After drying, the jerky
slices were held in the dehydrators overnight to allow the moisture
level in the jerky slices to equilibrate.

Inoculation procedure. Each of the two sides of each dried
jerky slice was inoculated with 0.2 ml of the composite Salmo-
nella inoculum and spread onto the entire surface area with a
sterile bent glass rod while the slice was held with sterile forceps.
After each side had been inoculated, slices were held at ambient
temperature for 30 min to allow bacteria to attach to the surface
of the jerky. The total inoculum volume of 0.4 ml per slice was
adequate for the delivery of the target level of bacteria (ca. 5.7
cf.u./cm2) without rehydration of the product. After inocula-
tion, slices from each treatment were placed in sterile plastic bags
(10 slices per bag) (Nasco, Fort Atkinson, Wis.) for aerobic stor-
age at ambient temperature (25 ± 1°C) for 60 days, as jerky prods
might be stored in consumers’ homes.

Sample analysis. During storage, samples were analyzed for
surviving microbial populations, pH, and water activity (aw).
Two samples (one slice per sample) per treatment were aseptically
transferred into 18-oz (ca. 532-ml) sterile plastic bags (Nasco,
Modesto, Calif.) after inoculation (day 0 following drying) and
on storage days 7, 14, 28, 42, and 60. Each sample was pummeled
for 2 min (120 strikes per min) after 25 ml of 0.1% sterile buffered
peptone water (BPW; Difco) was added. Serial decimal dilutions
were made with 9-ml BPW tubes, and 0.1-ml portions were sur-
face plated onto each of the duplicate plates of each agar medium.
Bacterial populations were determined on tryptic soy agar (Difco)
supplemented with 0.1% sodium pyruvate (Fisher Scientific) (TSAP)
(19) and on xylose-lysine-tergitol 4 (XLT4) agar (Difco). All plates
were incubated at 35°C for 48 h. The detection limit was ~0.4 log CFU/cm². When numbers of bacteria dropped be-
low the detection limit on XLT4 medium, enrichment of samples was
conducted. Briefly, after direct plating, the remaining portion of
the pummeled sample with 25 ml of BPW was incubated in the
sample bag at 35°C for 24 h. Next, 0.5- and 0.1-ml portions were
transferred to 10 ml of tetrathionate broth (Difco) and Rapp-
paport-Vassiliadis broth (Difco), respectively, and incubated at
42°C for 24 h. These cultures were then streak plated onto brilliant
green sulfa agar (Difco) and XLT4 agar and incubated at 35°C for
24 to 48 h, and plates were examined for characteristic (black)
colonies.

The pH values for samples (which had been supplemented
with 25 ml of BPW and pummeled for 2 min) were determined
with a digital pH meter (Accumet 50, Fischer Scientific, Houston,
Tex.) with a glass pH electrode (Hanna Instruments, Ann Arbor,
Mich.) at each sampling interval. The aw values for beef slices
determined on storage days 0, 28, and 60 with a water ac-
tivity meter (Model D2100, Rotronic Instrument Corp., Hun-
tington, N.Y.) according to AOAC International method
978.18 (22).
Statistical analysis. Two independent replicates of the study were conducted. Microbiological data were converted to log CFU/cm² values and evaluated with a factorial design (acid adaptation × number of replicates × predrying treatment × storage day × agar medium). Data were analyzed by analysis of variance for main (fixed) effects (acid adaptation, predrying treatment, drying time, and agar medium) and four-way interactions between acid adaptation, predrying treatment, storage time, and agar medium with the Statistical Analysis System (version 6.1, SAS Institute Inc., Cary, N.C.). Least-squares means were separated by Fisher’s least significance difference procedure with the use of the general linear models (GLM) procedure of SAS. A significance level of 0.05 was used for all statistical analyses. Standard deviations were calculated for the pH and a_w data.

RESULTS

Effects of agar media. Populations of bacteria recovered with TSAP from C- and TM-treated samples inoculated with acid-adapted cultures were significantly (P < 0.05) larger than those recovered with XLT4 agar throughout the storage period (Fig. 1). Counts obtained with TSAP counts were also significantly (P < 0.05) higher than those obtained with XLT4 agar for about the same period in MM-, AATM-, and TWTM-treated products when these products had been inoculated with nonadapted cultures (Fig. 2) but not when they had been inoculated with acid-adapted cultures (Fig. 1). These results suggest that the MM, AATM, and TWTM treatments were more lethal to acid-adapted cultures (Fig. 1) than to nonadapted cultures (Fig. 2) and that they caused more injury to nonadapted bacteria than to acid-adapted bacteria during storage (Figs. 1 and 2). In contrast, the C and TM treatments caused more injury to acid-adapted cells (Fig. 1) than to nonadapted cells (Fig. 2). The lack of significant differences between counts obtained with TSAP and those obtained with XLT4 agar for C- and TM-treated products inoculated with nonadapted cultures indicates that no bacterial injury occurred in these products during the 60-day storage period (Fig. 2). Although the recovery of injured cells is not expected during the storage of jerky, injured cells may contaminate the environment and other foods and recover to become a health concern.

Effects of storage. For samples subjected to each treatment, populations of acid-adapted bacteria decreased faster than those of nonadapted bacteria during storage (Figs. 1 and 2). Although the MM, AATM, and TWTM treatments caused overall faster declines in bacterial counts than the C and TM treatments did, the effectiveness levels of the former three treatments differed, particularly for products inoculated with nonadapted bacteria. More specifically, counts of nonadapted bacteria recovered from TWTM products with XLT4 agar were significantly (P < 0.05) lower than those recovered from MM products on storage days 7, 14, and 28. The XLT4 agar counts for TWTM products were also significantly (P < 0.05) lower than those for AATM products on storage day 14 (Fig. 2).

Regardless of the acid-adaptation status of cultures used to inoculate products or the recovery culture medium used during product storage, bacterial counts for C and TM products remained detectable by direct plating on XLT4 agar throughout the 60-day storage period. Bacterial counts on XLT4 agar decreased to below the detection limit (–0.4 log CFU/cm²) by day 14 for TWTM products and on day 60 for AATM products inoculated with nonadapted cultures (Fig. 2). The bacteria became undetectable on day 28 for
FIGURE 2. Survival of bacteria during 25°C storage of beef jerky inoculated after drying with non-acid-adapted Salmonella. The jerky was subjected to various predrying treatments and then dried at 60°C for 10 h ($n = 4$). Counts were determined on TSAP (A) and on XLT4 agar (B). Treatments: C, no predrying treatment or marinade prior to refrigeration at 4°C for 24 h and drying; TM, marination with traditional marinade (pH 4.3) prior to refrigeration at 4°C for 24 h and drying; MM, marination with modified marinade (1.2% lactate, 9% acetic acid, and soy sauce with 5% ethanol) (pH 3.0) prior to refrigeration at 4°C for 24 h and drying; AATM, dipping into 5% acetic acid solution (pH 2.5) for 10 min followed by marination with traditional marinade; TW/TM, dipping into 1% Tween 20 (pH 6.6) for 15 min and then into 5% acetic acid solution for 10 min followed by marination with traditional marinade prior to refrigeration at 4°C for 24 h and drying; 0, after inoculation, following drying. Vertical bars represent standard deviations of means. TW/TM-treated samples were first found to be Salmonella-negative by enrichment on storage day 28; C-, TM-, MM-, and AATM-treated samples that reached the detection limit ($-0.4$ log CFU/cm$^2$) were not found to be Salmonella-negative by enrichment.

TW/TM products and by day 42 for AATM and MM products inoculated with acid-adapted cultures (Fig. 1). In products inoculated with non-acid-adapted cultures, complete elimination of Salmonella (as indicated by a negative result with enrichment) was achieved only for TW/TM samples on day 28 (Fig. 2), whereas for products inoculated with acid-adapted cultures, samples were Salmonella-negative by enrichment on days 42, 42, and 60 for the TW/TM, AATM, and MM treatments, respectively (Fig. 1). Total reductions of bacteria after 60 days of storage for products inoculated with nonadapted Salmonella, as determined with nonselective (TSAP) and the selective (XLT4) media, were 3.3 and 3.9 log units for the C treatment, 2.9 and 3.3 log units for the TM treatment, 5.0 and 5.6 log units for the MM treatment, 5.5 and 5.8 log units for the AATM treatment, and 5.6 and 6.0 log units for the TW/TM treatment, respectively. Corresponding reductions for products inoculated with acid-adapted cultures were 5.1 and 5.5 log units for the C treatment, 5.1 and 6.0 log units for the TM treatment, 5.8 and 6.1 log units for the MM treatment, 4.9 and 6.2 log units for the AATM treatment, and 5.4 and 6.3 log units for the TW/TM treatment.

Product pH and $a_w$: pH values for jerky slices subjected to the MM (pH 4.41 to 4.90), AATM (pH 4.54 to 4.86), and TW/TM (pH 4.44 to 4.82) treatments were lower than those for slices subjected to the C (pH 5.41 to 6.02) and TM (pH 5.22 to 5.80) treatments (Table 1). The $a_w$ values for products were in the range of 0.560 and 0.688 (Table 2) for all treatments. During storage, pH values increased slightly for all products and $a_w$ values fluctuated somewhat, with many samples picking up some moisture during the 60 days of aerobic storage. Because these effects would not be expected to account for differences in bacterial count reductions among treatments during storage, it is likely that the marination treatments used in the preparation of the jerky products played the main role in reductions (via injury or death) in populations of bacteria inoculated after drying.

DISCUSSION

Salmonella has been reported to accumulate glutamate and proline in order to survive under osmotic stress (3, 8, 20). It has been suggested that Salmonella may survive better than yeasts and staphylococci but not as well as enterococci and bacilli on dried Chinese meats and South African biltong, another type of dried meat product (17). Juven et al. (15) used a five-tube most probable number method to evaluate the survival of Salmonella in dry foods (dry milk, cocoa powder) or dry feed (meat and bone meal, poultry feed) with adjusted $a_w$ values (0.40, 0.52, and 0.75) over 14 weeks of storage at 25°C. Juven et al.’s results indicated that Salmonella survived better at low $a_w$ values (0.40 and 0.52) than at a relatively higher $a_w$ value (0.75) in all foods. In addition, periods during which viable Salmonella cells were detected varied widely (from 1 [cocoa powder] to 14 weeks [dry milk, meat and bone meal]), even when the $a_w$ values for the food or feed were similar. Juven et al. concluded that the survival of Salmonella in dry food or feed could not be predicted by $a_w$ alone. Similarly, the results of the present study indicate that the survival of Salmonella in jerky products of similar $a_w$ values differed among products subjected to different predrying treatments and between products inoculated with acid-adapted cultures and those inoculated with nonadapted cultures. In general, declines in and the elimination of Salmonella populations...
TABLE 1. Mean pH values (n = 4) for beef jerky during storage at 25°C for 60 daysa

<table>
<thead>
<tr>
<th>Storage time (days)</th>
<th>Mean (SD) pH for jerky inoculated with acid-adapted Salmonella</th>
<th>Mean (SD) pH for jerky inoculated with nonadapted Salmonella</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>TM</td>
</tr>
<tr>
<td>0</td>
<td>5.55 (0.40)</td>
<td>5.28 (0.02)</td>
</tr>
<tr>
<td>7</td>
<td>6.02 (0.11)</td>
<td>5.76 (0.14)</td>
</tr>
<tr>
<td>14</td>
<td>5.84 (0.37)</td>
<td>5.80 (0.30)</td>
</tr>
<tr>
<td>28</td>
<td>5.61 (0.02)</td>
<td>5.58 (0.05)</td>
</tr>
<tr>
<td>42</td>
<td>5.74 (0.10)</td>
<td>5.64 (0.12)</td>
</tr>
<tr>
<td>60</td>
<td>5.63 (0.21)</td>
<td>5.60 (0.23)</td>
</tr>
</tbody>
</table>

a The jerky was subjected to various predrying marination treatments before drying at 60°C for 10 h and was then inoculated with acid-adapted or nonadapted Salmonella. C, not treated or marinated prior to refrigeration at 4°C for 24 h and drying; TM, marinated with traditional marinade (pH 4.3), held at 4°C for 24 h, and then dried; MM, marinated with modified marinade (1.2% lactate, 9% acetic acid, and soy sauce with 5% ethanol) (pH 3.0), held at 4°C for 24 h and then dried; AATM, dipped into 5% acetic acid solution (pH 2.5) for 10 min at ambient temperature, drained for 2 min, and then marinated with traditional marinade; TWTM, dipped into 1% Tween 20 (pH 6.6) for 15 min, and then dipped into 5% acetic acid solution for 10 min at ambient temperature, then marinated with traditional marinade.

were faster in products subjected to the TWTM, AATM, and MM treatments than in products subjected to the C and TM treatments, indicating potential antimicrobial activity arising from the properties of these treatments or the ingredients involved. The strong antimicrobial effects of the TWTM, AATM, and MM treatments relative to those of the C and TM treatments during storage at 25°C were probably the result of additional hurdles, such as a lower pH. It is hypothesized that the low-pH environment may have led to a reduced osmolyte accumulation in the bacterial cytoplasm, since the bacteria were under osmotic stress (23). In addition, the disruption of pH homeostasis (MM) (5, 14) or weaker attachment of bacteria to the food surface because of presence of a surfactant (TWTM) (4) may have resulted in an increase in the sensitivity of bacteria to hurdles such as low pH.

Acid adaptation has been reported to enhance the survival of Salmonella in acidic foods and to increase cross-protection from other types of stresses, such as heat (5, 19, 21, 24, 25). A concern associated with this phenomenon is that acid-adapted or stressed pathogens may exhibit lower infectious doses and increased virulence, since it has been hypothesized that numbers of enteric bacteria that are resistant to acid may not be reduced significantly by the acidity

TABLE 2. Mean aw values (n = 4) for beef jerky during storage at 25°C for 60 daysa

<table>
<thead>
<tr>
<th>Storage time (days)</th>
<th>Mean (SD) aw value for jerky inoculated with acid-adapted Salmonella</th>
<th>Mean (SD) aw value for jerky inoculated with nonadapted Salmonella</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>TM</td>
</tr>
<tr>
<td>0</td>
<td>0.651 (0.001)</td>
<td>0.601 (0.038)</td>
</tr>
<tr>
<td>28</td>
<td>0.648 (0.004)</td>
<td>0.629 (0.006)</td>
</tr>
<tr>
<td>60</td>
<td>0.635 (0.021)</td>
<td>0.648 (0.011)</td>
</tr>
</tbody>
</table>

a The jerky was subjected to various predrying marination treatments before drying at 60°C for 10 h and was then inoculated with acid-adapted or nonadapted Salmonella. C, not treated or marinated prior to refrigeration at 4°C for 24 h and drying; TM, marinated with traditional marinade (pH 4.3), held at 4°C for 24 h, and then dried; MM, marinated with modified marinade (1.2% lactate, 9% acetic acid, and soy sauce with 5% ethanol) (pH 3.0), held at 4°C for 24 h and then dried; AATM, dipped into 5% acetic acid solution (pH 2.5) for 10 min at ambient temperature, drained for 2 min, and then marinated with traditional marinade; TWTM, dipped into 1% Tween 20 (pH 6.6) for 15 min, and then dipped into 5% acetic acid solution for 10 min at ambient temperature, then marinated with traditional marinade.
of the gastric environment (9). In this study, however, the acid-adapted *Salmonella* cultures introduced on the products after drying were found to be significantly more sensitive than the nonadapted cells. This difference might be the result of multiple hurdles, such as high acidity, low $a_w$, and increased oxidation reduction potential in these jerky products. It may also be speculated that the level of cross-protection arising from acid adaptation is dependent on the presence and severity of other stress factors as a function of time. It seems that acidity (e.g., pH 4.8) and low $a_w$ (<0.800) during storage at a growth-permitting temperature (25°C) constituted combinations that could overcome any cross-protection provided by acid adaptation. Another conjecture that may be advanced to explain the stronger sensitivity of acid-adapted cultures is that such cultures may have a greater nutrient (glucose) load carryover than nonadapted inocula, which could lead to a higher level of metabolic exhaustion and premature death upon exposure to the stress of dry conditions and other hurdles (provided, however, that metabolism is feasible under the dry conditions of the products inoculated with stationary-phase cells).

In conclusion, the results of this study indicate that the endurance of postprocessing *Salmonella* contamination on jerky during storage was greatly affected by the type of pre-drying treatment to which the jerky was subjected and by the history of the culture with which the jerky was inoculated, since the treatments were more lethal to acid-adapted inocula. The use of predrying marinade treatments containing Tween 20, acetic acid, lactate, and/or ethanol provided antimicrobial effects during storage resulting in faster inactivation of *Salmonella* introduced on the jerky after drying. Practically, populations of *Salmonella* present on jerky after drying may be reduced from approximately 5.7 log CFU/cm$^2$ to below the detection limit ($\sim$0.4 log CFU/cm$^2$) in 14 to 60 days of storage if jerky products are marinated with a marinade (pH 3.0) modified with acid and ethanol (MM), subjected to a two-step process involving dipping into household vinegar (5% acetic acid) followed by marination with a traditional marinade (AATM), or subjected to a three-step process involving sequential dipping into 1% Tween 20 solution and 5% acetic acid followed by marination with a traditional marinade (TWTM), depending on the acid-adaptation status of the culture, while they may remain detectable by direct plating for products not treated with marinade (C) and for products treated with traditional marinade (TM), even after 60 days of storage. All three modified products have commercial processing application potential, and the MM and AATM products could easily be prepared in a home setting with the use of readily available ingredients. While limited preliminary evaluation indicated that products subjected to each treatment were acceptable for consumption, additional studies are needed to better evaluate the effects of these treatments on product palatability.

**ACKNOWLEDGMENTS**

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