Effect of Ethanol Rinse, *Lactobacillus fermentum* Inoculation, and Modified Atmosphere on Ground Chicken Meat Quality

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**ABSTRACT** Ground chicken breast meat was prepared using combinations of the following treatments: ethanol rinse before grinding, inoculation with *Lactobacillus fermentum* after grinding, and modified atmosphere packaging in either 90% O2 and 10% CO2 or 90% N2 and 10% CO2. Control treatments included water rinse and noninoculation with *L. fermentum*. Packaged meat was refrigerated and sampled for various shelf-life quality indices on d 0, 3, and 6. The inoculation with *L. fermentum* had little or no effect on ground meat shelf life. The ethanol-rinsed meat had lower off-odor scores and lower microbial growth compared to nonethanol rinsed meat. The high-N2 atmosphere maintained meat color better than the high-O2 packaging, but there was no effect on microbial growth. The combination of ethanol rinsing and high-N2 packaging extended ground chicken quality compared with meat rinsed in water and packaged in high O2.

**Key words**: ground chicken, modified atmosphere packaging, *Lactobacillus fermentum*, ethanol

**INTRODUCTION**

The shelf life of raw poultry meat is affected by pH, meat type, gas environment, temperature, and the number and type of microorganisms present (Mead, 1983). Grinding of meat promotes microbial growth by distributing microorganisms throughout the meat (Collins et al., 1995) and by the release of purge. Minimizing the number of bacteria on the meat surface before grinding would reduce the number of bacteria distributed throughout the meat during grinding. Brown and Tischer (1967) stated that 50 to 70% ethanol concentrations were disinfecting agents and that higher ethanol concentrations could, in some cases, desiccate cells, making them more resistant to chemical and physical disinfection. However, Lueck (1980) reported that lower concentrations of ethanol (5 to 20%) inhibited microbial growth by lowering water activity. Hall and Spencer (1964) and Tsou (1995) reduced the microbial population on intact chicken meat by rinsing the meat with 70 and 50% ethanol, respectively. Color stability of ground meat is an important product attribute in the retail market. Arihara et al. (1993) reported that *Lactobacillus fermentum* JCM 1173 produced NO and converted metmyoglobin to NO myoglobin to help retain the red color of meat. Modified atmosphere packaging (MAP) is used by the meat industry to preserve the characteristic bright red color of fresh meat. Carbon dioxide has also been shown to inhibit the growth of spoilage bacteria on meat (Devlieghere and Debevere, 2000). Robertson (1993) classified MAP into 2 general categories: low-O2 MAP (vacuum packaging, CO2 flushing, N2 flushing) and high-O2 MAP. Stiles (1991) summarized the role of MAP gases in meat packaging as follows: CO2 providing a bactericidal and static effect, O2 maintaining fresh meat color, and N2 acting as a filler and purge reducer. The combination of the aforementioned treatments may extend the shelf life of ground meat. Thus, the objective of the present study was to determine the effect of a 30% (vol/vol) ethanol rinse, *L. fermentum* inoculation, and MAP (high O2 and high N2) to extend the shelf life of ground chicken meat.

**MATERIALS AND METHODS**

Fresh boneless chicken breast delivered the previous day from the poultry supplier was purchased from a local retailer and immediately brought to the laboratory. Breast meat was cut into approximately 1-inch (2.54 cm) cubes using a sterile knife. The meat cubes were separated into two 6-kg lots, which were then rinsed in 4 L of either chilled (~5°C) distilled water or 30% (vol/vol) ethanol for 5 min while being stirred with a sterile spoon. All meat was then drained for 1 min and then rinsed again for 1 min in distilled water. Meat cubes were drained before being ground through a 4-mm plate. Ground meat from each rinse treatment was then separated into 2 lots of approximately 3 kg each, one of which was inoculated with approximately 3.3 × 10⁶ cfu/g of *L. fermentum* (ATCC
The L. fermentum inoculum was initially taken from an agar slant culture and inoculated into liquid deMan, Rogosa, and Sharpe (MRS) medium then incubated at 37°C for 24 h. Additionally, 0.1 mL of the 24-h culture was transferred into 100 mL of MRS broth and incubated at 37°C for 18 h to give approximately a \(10^8\) cfu/mL culture. The 18-h culture was centrifuged for 30 min and the pellet washed 3 times before being hand-mixed into 3 kg of ground meat. This yielded approximately \(1 \times 10^{10}\) total cells into 3,000 g of meat or about \(3.3 \times 10^6\) cfu/g. Two hundred twenty-five grams of ground meat from each treatment combination was packaged in expanded polystyrene trays with a volume of 550 mL. This resulted in approximately a 2:1 package headspace:meat volume ratio. One of 2 gas package atmospheres was used: 90% O₂:10% CO₂ (high O₂) or 90% N₂:10% CO₂ (high N₂). The containers were heat-sealed with a barrier stretch film having an O₂ transmission rate of less than 30 mL of O₂/m² per 24 h and then stored in a lighted refrigerator (4°C ± 2°C). Meat was sampled for package gas headspace composition, pH, color, bacterial population, and odor on d 0, 3, and 6 of refrigerated storage (4°C ± 2°C).

**Package Gas Headspace**

A 500-μL sample of gas package headspace was drawn by syringe through a silicon septum attached to the package film surface. The gas sample was injected into a gas chromatograph (Gow-Mac series 580, Gow-Mac Instrument Co., Bethlehem, PA) with a CTR column (catalog number 8700, Alltech Associates, Deerfield, IL) held at a constant temperature of 30°C. The injection temperature was 100°C, and gases were detected using a thermal conductivity detector held at 100°C. The carrier gas was He with a flow rate of 60 mL/min, and the percentage of CO₂, O₂, and N₂ was calculated from the detector response.

**Color**

Meat color was measured using a Minolta chroma meter (CR-300, Minolta Corp., Ramsey, NJ). Surface color was measured at 5 different locations. Three sides of the packaging film were cut so that the colorimeter orifice could be pressed against the package film and meat surface smoothly. Color readings were taken through the film, and the films color attributes were subtracted from the readings automatically. International Commission on Illumination (Commission Internationale de L’Eclairage) lightness (L*), redness (a*), and yellowness (b*) values were recorded, and hue angles (arc tangent of b*/a*) were calculated.

**Bacterial Counts**

Total aerobic plate counts were determined using plate count agar media (Difco Microbiology, Becton, Dickinson and Co., Franklin Lakes, NJ) and lactobacilli species counts were enumerated on MRS media (Difco Microbiology, Becton, Dickinson and Co.). Ten grams of meat was weighed into a sterile filtered stomacher bag before adding 90 mL of 0.1% sterile peptone water (Difco Microbiology, Becton, Dickinson and Co.). The contents were homogenized in a stomacher (Tekmar Co., Cincinnati, OH) for 2 min. Serial dilutions were made in sterile peptone water, then dilutions were plated in either plate count agar or MRS agar. Total aerobic plates were incubated (Napco model 332, National Appliance Co., Heinickey Co., Portland, OR) at 35°C for 48 h. Lactobacilli plates were incubated under 5% CO₂ at 37°C for 48 h (model 2300, VWR Scientific Products, West Chester, PA). All plating was performed in duplicate, and dilutions resulting in plates with from 25 to 250 colonies were counted and the results converted to base-10 logarithm colony-forming units per gram of original meat sample.

**Odor Evaluation**

Evaluation of meat odor was conducted immediately after opening the package using an off-odor scale as follows: 1 = normal odor; 2 = slightly perceptible off-odor; 3 = perceptible off-odor; 4 = slightly pronounced off-odor; and 5 = pronounced off-odor. Panelists were experienced with off-odor evaluation and participated in 3 training sessions for detecting the off-odor of aged chicken breast meat. Six panelists evaluated all samples on all days. The odor evaluation used the following procedure: Each package film was cut in the corner of the tray, and then each panelist was asked to lift the film at the opened corner, sniff, then record off-odor perception of the sample. Off-odor evaluation was conducted immediately after taking the meat samples out of refrigeration.

**pH Measurement**

Meat pH was determined by blending 10 g of ground chicken meat in a jar with 100 mL of distilled water for 2 min. The pH was determined by placing an electrode attached to a pH meter (model 420 A, Orion Inc., Boston, MA) in the meat suspension and then reading the pH value from the digital display.

**Statistical Analysis**

The experimental design was a 2 × 2 × 2 × 3 split plot (2 rinsing treatments, 2 inoculation treatments, 2 MAP treatments, and 3 storage evaluation times). A GLM was applied to obtain the ANOVA, and when treatments were found to be significant (\(P \leq 0.05\)), means were separated and error determined using the lsmeans/pdiff stderr statement of SAS (SAS release 8.0, SAS Institute, 2002). The experiment was replicated twice on different days with 2 different lots of meat.

**RESULTS AND DISCUSSION**

**Package Headspace**

When the data were pooled, meat packaged in high O₂ had greater CO₂ concentration (17.9%; \(P \leq 0.05\)) in the
package headspace after 6 d of storage than meat packaged in high N₂ (7.4% CO₂). Water-rinsed meat also had higher package headspace CO₂ concentration (16.9%) compared with ethanol-rinsed meat (8.3% CO₂). The 2 treatment combinations showing high CO₂ concentrations at 6 d are those treatments that included neither ethanol rinse nor high-N₂ MAP (Figure 1). The presence of O₂ promotes the growth of aerobic microorganisms that consume O₂ and produce CO₂ (Butler et al., 1953). Carbon dioxide is produced via glucose metabolism by both aerobic and anaerobic bacteria (Ray, 1992). Daun et al. (1971) observed that CO₂ was generated immediately after packaging, and CO₂ levels increased through the first few days of storage but reached a constant level with 8 to 9 d of storage. The same researchers reported that increases in CO₂ paralleled bacterial growth and that more CO₂ was produced than O₂ in packaged meat samples. A similar trend was observed in the present study with the 2 treatments not including ethanol rinse or high-N₂ MAP displaying a decrease in O₂ at d 6 compared with the high-O₂ treatments that were rinsed in 30% ethanol (Figure 2). Satterlee and Hansmeyer (1974) found a high O₂ demand on the meat surface when total microbial loads were high. Zhao et al. (1995) reported that the adsorption of CO₂ into fresh meat caused a decrease in headspace volume in MAP meat, resulting in package collapse. Package collapse was observed in meat packaged in high O₂. The concave film surface was even more...

Figure 1. Means for CO₂ concentration for meat packaged in either high O₂ or high N₂ at 0, 3, and 6 d of refrigerated storage (4 ± 1°C). Water = water rinse; ethanol = ethanol rinse; inoculated = inoculated with Lactobacillus fermentum; not inoculated = not inoculated with L. fermentum; O₂ = packaged in a gas atmosphere of 90% O₂ and 10% CO₂; N₂ = packaged in a gas atmosphere of 90% N₂ and 10% CO₂. **Mean data points with the same letter do not significantly differ (P > 0.05).

Figure 2. Means for O₂ concentration for meat packaged in either high O₂ or high N₂ at 0, 3, and 6 d of refrigerated storage (4 ± 1°C). Water = water rinse; ethanol = ethanol rinse; inoculated = inoculated with Lactobacillus fermentum; not inoculated = not inoculated with L. fermentum; O₂ = packaged in a gas atmosphere of 90% O₂ and 10% CO₂; N₂ = packaged in a gas atmosphere of 90% N₂ and 10% CO₂. **Mean data points with the same letter do not significantly differ (P > 0.05).
higher than noninoculated meat. Inoculation with 6, the inoculated samples were still about 1 log cycle than that for noninoculated samples (Table 1). By d increased the total aerobes in both high-N2-and fmentum the number of microorganisms exceeds 108 cells/g (Gill, of minced meat products is generally detectable when package headspace atmosphere (Table 1). The spoilage counts at 3 and 6 d for noninoculated meat regardless of total plate counts for inoculated treatments, it did reduce and those for meat packaged in high O2 had decreased to a degree that high-N2-packaged meat had the greater a* values (Table 2). The loss of red color by the meat packaged in high O2 is due to a loss of oxymyoglobin and an increase in metmyoglobin as the predominant pigment. This reaction occurs more rapidly in high-O2 environments compared with those lacking O2 due to oxidation of the Fe moiety from the +2 to +3 state. The a* value has been positively correlated with total pigment, myoglobin, and Fe concentration in meat (Boulainne and King, 1995). Andersen et al. (1988) suggested that Hunter a* values were more highly correlated to meat (ham) redness than L* or b* values. In the present study, N2-packaged meat had lower L* values compared with O2-packaged meat at 3 and 6 d. Lower L* and higher a* values indicate a superior fresh beef color (Manu-Tawiah et al., 1991), partly due to a decrease in visible pigment concentration, which results in an increase in meat lightness (Boulainne and King, 1995). MacDougall (1982) found that an increase in L*, either from a decrease in pigment concentration or an increase in scatter, is accompanied by an increase in hue angle from red to yellow.

Hue angle, representing the arc tangent of b*/a*, increases from 0 to 90 degrees, indicating a change in color from red to yellow. The MAP treatment significantly affected the hue angle of meat (P ≤ 0.05), with the high-O2 environment having a greater increase in hue angle during storage compared with high-N2-packaged meat. The higher a* values and lower L* values for meat packaged in high N2 reflect visual observations that meat packaged in high N2 had a superior and more fresh-like appearance than meat stored in high O2. This finding was previously reported by Seideman et al. (1979) for steak, in which meat packaged in 100% O2 had greater surface discoloration than meat packaged in 100% CO2 or 100% N2. Sante et al. (1994) also found that turkey breast meat packed in either 100% CO2 with an O2 scavenger or under vacuum had better color during storage compared with meat packaged in ambient atmospheres. Ogilvy and Ayres (1951) reported that CO2 concentrations from 15 to 25% were related to discoloration of chicken meat. Simard et al. (1985) concluded that N2 improved the shelf life of beef by retarding discoloration, while Saucier et al. (2000) found that mechanically deboned chicken and turkey meat packed in a high-O2 barrier film (O2 transmission rate < 35 mL/m2 per 24 h at 25°C) in a atmosphere of 80% N2 and 20% CO2 maintained a better appearance than meat packed in an atmosphere of 62% CO2, 8% O2, and 30%N2. Chicken breast meat has a relatively high O2 consumption rate (OCR) compared with other meat types, resulting in less opportunity to “bloom” (Millar et

### Table 1. Mean base-10 logarithms of total plate counts for ground chicken meat rinsed in 30% ethanol or water, inoculated or not inoculated with Lactobacillus fermentum, and packaged in 90% O2 or 90% N2 and stored 3 d under refrigeration (4 ± 1°C)

<table>
<thead>
<tr>
<th>Treatment1</th>
<th>0 d</th>
<th>3 d</th>
<th>6 d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water-not inoculated-O2</td>
<td>4.17a</td>
<td>6.44b</td>
<td>9.37a</td>
</tr>
<tr>
<td>Water-not inoculated-N2</td>
<td>4.17a</td>
<td>6.85b</td>
<td>9.89a</td>
</tr>
<tr>
<td>Water-inoculated-O2</td>
<td>4.18a</td>
<td>8.45a</td>
<td>9.36b</td>
</tr>
<tr>
<td>Water-inoculated-N2</td>
<td>4.18a</td>
<td>8.54a</td>
<td>9.26b</td>
</tr>
<tr>
<td>Ethanol-not inoculated-O2</td>
<td>4.33a</td>
<td>5.45a</td>
<td>7.75b</td>
</tr>
<tr>
<td>Ethanol-not inoculated-N2</td>
<td>4.33a</td>
<td>6.31a</td>
<td>7.08b</td>
</tr>
<tr>
<td>Ethanol-inoculated-O2</td>
<td>4.40a</td>
<td>8.30a</td>
<td>9.02a</td>
</tr>
<tr>
<td>Ethanol-inoculated-N2</td>
<td>4.40a</td>
<td>8.54a</td>
<td>9.11a</td>
</tr>
</tbody>
</table>

**Note:** Means under the same day followed by the same letter do not significantly differ (P > 0.05); n = 12.

1Water = water rinse; ethanol = ethanol rinse; inoculated = inoculated with L. fermentum; not inoculated = not inoculated with L. fermentum; O2 = packaged in a gas atmosphere of 90% O2 and 10% CO2; N2 = packaged in a gas atmosphere of 90% N2 and 10% CO2.

### Bacterial Counts

After 3 d of storage, the total aerobic plate count for inoculated samples was nearly 2 log cycles higher (P ≤ 0.05) than that for noninoculated samples (Table 1). By d 6, the inoculated samples were still about 1 log cycle higher than noninoculated meat. Inoculation with L. fermentum increased the total aerobes in both high-N2- and high-O2-packaged meat. Lactobacillus fermentum is classified as a facultative anaerobic bacterium; therefore, growth is possible in both package headspace atmospheres. Although ethanol rinsing had no effect on the total plate counts for inoculated treatments, it did reduce counts at 3 and 6 d for noninoculated meat regardless of package headspace atmosphere (Table 1). The spoilage of minced meat products is generally detectable when the number of microorganisms exceeds 10⁸ cells/g (Gill, 1983) and growth of psychrophiles continues under refrigeration (Barnes, 1976). High-N2 atmosphere has been shown to reduce purge in packages of intact chicken, which subsequently slowed bacterial growth (Rhee et al., 2006).

Meat spoilage is also related to discoloration (Robach and Costlow, 1961); however, Kraft and Ayres (1952) concluded that discoloration of packaged red meat was not correlated to other spoilage indices such as bacterial growth. Daun et al. (1971) stated that the initial formation of metmyoglobin is independent of microbial growth, and Faustman et al. (1990) found that meat color change was not necessarily indicative of the number of microorganisms in meat. Butler et al. (1953) did find that the rate of metmyoglobin formation was greatest during the bacterial logarithmic growth phase.
Odor Evaluation

Generally, off-odors reached an unacceptable level when bacterial numbers reached approximately $10^8$ cells/g. These odors were more pronounced in meat stored in high N$_2$ (Table 3). However, ethanol rinsing reduced the off-odors detected at d 6 regardless of inoculation or MAP treatment. McMeekin (1975) found 3 distinctive off-odors in spoiled chicken meat identified as “sulfide-like,” “fruity,” and “evaporated milk.” In an O$_2$ atmosphere of 10 to 20%, the volatile compounds found in packaged chicken broiler carcasses were mainly alcohols and carbonyl compounds (Viehweg et al., 1989). The concentration of these compounds increased until the onset of spoilage on d 6 when spoilage aroma compounds were H$_2$S, CH$_3$S, esters, fatty acids, and aliphatic alcohols. Pierson et al. (1970) concluded that *Pseudomonas* species were responsible for putrefaction, while lactic acid bacteria caused sour or acidic off-flavors. Gill (1983) reported that *Brochothrix thermosphaeta* participated in both aerobic and anaerobic spoilage, producing acetion from aerobic carbohydrate metabolism and volatile fatty acids from amino acids. Gill (1983) also found that in meat with a pH $\geq 6.0$, *Shewanella putrefaciens* could produce H$_2$S. Lee and Simard (1984) also reported that many lactobacilli strains could produce H$_2$S.

Finally, lipid oxidation in high-O$_2$ environments may contribute to meat color and flavor stability. Allen and Foegeding (1981) concluded that food lipids contribute to flavor, color, and texture shelf life. Lipid oxidation may promote oxidation of myoglobin to metmyoglobin, negatively affecting meat color.

**pH**

Jaye et al. (1962) concluded that the decrease in pH of spoiled meat was due to the growth of lactic acid bacteria, while an increase in pH during meat spoilage was related to proteolysis by fluorescent *Pseudomonas* species. Thus, in the current study, the high-O$_2$ and high-N$_2$ environments would be expected to have different effects on meat pH.

**Odor Evaluation**

Table 3. Mean off-odor scores for ground chicken meat rinsed in 30% ethanol or water, inoculated or not inoculated with *Lactobacillus fermentum*, and packaged in 90% O$_2$ or 90% N$_2$ and stored 3 d under refrigeration (4 ± 1°C).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>d 0</th>
<th>d 3</th>
<th>d 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water-not inoculated-O$_2$</td>
<td>1.0$^a$</td>
<td>1.1$^c$</td>
<td>5.0$^d$</td>
</tr>
<tr>
<td>Water-not inoculated-N$_2$</td>
<td>1.0$^a$</td>
<td>2.3$^b$</td>
<td>5.0$^a$</td>
</tr>
<tr>
<td>Water-inoculated-O$_2$</td>
<td>1.0$^a$</td>
<td>1.3$^bc$</td>
<td>2.9$^d$</td>
</tr>
<tr>
<td>Water-inoculated-N$_2$</td>
<td>1.0$^a$</td>
<td>2.1$^b$</td>
<td>5.0$^a$</td>
</tr>
<tr>
<td>Ethanol-inoculated-O$_2$</td>
<td>1.0$^a$</td>
<td>1.0$^d$</td>
<td>2.0$^d$</td>
</tr>
<tr>
<td>Ethanol-inoculated-N$_2$</td>
<td>1.0$^a$</td>
<td>1.4$^bc$</td>
<td>3.7$^d$</td>
</tr>
<tr>
<td>Ethanol-inoculated-O$_2$</td>
<td>1.0$^a$</td>
<td>1.3$^bc$</td>
<td>2.0$^d$</td>
</tr>
<tr>
<td>Ethanol-inoculated-N$_2$</td>
<td>1.0$^a$</td>
<td>1.8$^ab$</td>
<td>3.6$^d$</td>
</tr>
</tbody>
</table>

$^a$–$^d$Means under the same day followed by the same letter do not significantly differ ($P > 0.05$); n = 12.

$^1$Off-odor scoring: 1 = normal odor; 2 = slightly perceptible off-odor; 3 = perceptible off-odor; 4 = slightly pronounced off-odor; 5 = pronounced off-odor.

$^2$Water = water rinse; ethanol = ethanol rinse; inoculated = inoculated with *L. fermentum*; not inoculated = not inoculated with *L. fermentum*; O$_2$ = packaged in a gas atmosphere of 90% O$_2$ and 10% CO$_2$; N$_2$ = packaged in a gas atmosphere of 90% N$_2$ and 10% CO$_2$.

**pH**

Table 4. Mean pH values for ground chicken meat rinsed in 30% ethanol or water, inoculated or not inoculated with *Lactobacillus fermentum*, and packaged in 90% O$_2$ or 90% N$_2$ and stored 3 d under refrigeration (4 ± 1°C).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>d 0</th>
<th>d 3</th>
<th>d 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water-not inoculated-O$_2$</td>
<td>6.49$^a$</td>
<td>6.61$^a$</td>
<td>6.69$^a$</td>
</tr>
<tr>
<td>Water-not inoculated-N$_2$</td>
<td>6.49$^a$</td>
<td>6.47$^b$</td>
<td>6.49$^b$</td>
</tr>
<tr>
<td>Water-inoculated-O$_2$</td>
<td>6.49$^a$</td>
<td>6.55$^ab$</td>
<td>6.71$^a$</td>
</tr>
<tr>
<td>Water-inoculated-N$_2$</td>
<td>6.49$^a$</td>
<td>6.51$^ab$</td>
<td>6.51$^b$</td>
</tr>
<tr>
<td>Ethanol-not inoculated-O$_2$</td>
<td>6.48$^a$</td>
<td>6.49$^b$</td>
<td>6.46$^b$</td>
</tr>
<tr>
<td>Ethanol-not inoculated-N$_2$</td>
<td>6.48$^a$</td>
<td>6.43$^b$</td>
<td>6.48$^b$</td>
</tr>
<tr>
<td>Ethanol-inoculated-O$_2$</td>
<td>6.49$^a$</td>
<td>6.48$^b$</td>
<td>6.56$^b$</td>
</tr>
<tr>
<td>Ethanol-inoculated-N$_2$</td>
<td>6.49$^a$</td>
<td>6.46$^b$</td>
<td>6.49$^b$</td>
</tr>
</tbody>
</table>

$^a$–$^b$Means under the same day followed by the same letter do not significantly differ ($P > 0.05$); n = 12.

$^1$Water = water rinse; ethanol = ethanol rinse; inoculated = inoculated with *L. fermentum*; not inoculated = not inoculated with *L. fermentum*; O$_2$ = packaged in a gas atmosphere of 90% O$_2$ and 10% CO$_2$; N$_2$ = packaged in a gas atmosphere of 90% N$_2$ and 10% CO$_2$.
In fact, gas atmosphere did have an effect \((P \leq 0.05)\) on meat \(pH\) on d 3 and 6 (Table 4). However, \(pH\) values did not differ on d 0. The effect of gas atmosphere on \(pH\) was suppressed in ethanol-rinsed meat as might be expected, because ethanol should reduce initial microbial numbers and delay subsequent effects on \(pH\). Meat packed in high \(O_2\) that was not ethanol-rinsed was 0.2 \(pH\) units higher at d 6 than nonethanol-rinsed meat packed in high \(N_2\). Generally, the change in meat \(pH\) depends on several factors but is mostly affected by the production of metabolites from microbial growth or in some cases from biochemical reactions occurring in the meat tissue. Elliott et al. (1985) found that \textit{Pseudomonas} species were the predominant flora in spoiled chicken, and the proteolytic action of these organisms increased the meat surface \(pH\). Allen et al. (1997) found the broiler meat with higher \(pH\) resulted in a faster growth of \textit{Pseudomonas} species and spoilage than broiler meat having a lower inherent \(pH\). Farber (1991) stated that the release of \(H^+\) ions from the spoilage than broiler meat having a lower inherent \(pH\). Resulted in a faster growth of \textit{Pseudomonas} species and the proteolytic action of these organisms increased the meat surface \(pH\). Allen et al. (1997) found the broiler meat with higher \(pH\) resulted in a faster growth of \textit{Pseudomonas} species and spoilage than broiler meat having a lower inherent \(pH\). Farber (1991) stated that the release of \(H^+\) ions from the dissociation of \(H_2CO_3\) can cause a slight drop in \(pH\), while Hirsch (1991) further stated that dissolving \(CO_2\) not only forms \(H_2CO_3\) but also reduces internal package pressure, creating a partial vacuum. This may have contributed to the package collapse observed in the present study, especially in the water-rinsed meat packaged in high \(O_2\), because \(CO_2\) levels increased above 20% (Figure 1). In addition to being an indicator of aerobic spoilage, high \(pH\) meat encourages putrefactive microbial growth and accelerated respiratory action in the meat tissue (Renerre, 1990; Faustman, 1994). Rotobakk et al. (2006) minimized the collapse of tray-packed chicken by holding the meat in a high-\(CO_2\) atmosphere to increase the dissolution of and somewhat saturate the meat with \(CO_2\).

In summary, ethanol rinsing did maintain the quality of several shelf indices, including microbial growth, off-odor presence, and \(pH\) increase. Inoculation with \textit{L. fermentum} had no detectable effect on meat shelf life. It was theorized that this organism, which has been shown to stabilize meat color, would do so especially in the high-\(N_2\) atmosphere; however, this was not observed. Finally, the high-\(N_2\), gas-packaged environment maintained ground chicken meat color better than the high-\(O_2\) MAP. Although there was a stronger off-odor in the high-\(N_2\) packages when first opened, this odor dissipated rapidly. The combination of rinsing meat pieces with 30% ethanol solution before grinding coupled with a high-\(N_2\) MAP would be expected to extend the shelf life of ground chicken meat compared with current processing and packaging practices.

**REFERENCES**


