INTRODUCTION

Organic acids such as lactic acid, acetic acid, and citric acid are effective at reducing Salmonella spp., Escherichia coli, coliforms, and aerobic bacteria in poultry and meat processing. Organic acids work very well at inhibiting bacteria due to their ability to penetrate and disrupt the cell membrane and to acidify the cell contents (Keener et al., 2004). Carpenter and Broadbent (2009) explained that the inhibitory effects of weak acids can not only be attributed to the effects that they have on pH, but also to their effect on membrane function. The high levels of weak acid anions that accumulate in the cytoplasm cause an osmotic effect on the cell and metabolic processes that occur within the cytoplasm. Lactic acid, acetic acid, buffered lactic acid, and gluconic acid can all be applied as decontamina-
**MATERIALS AND METHODS**

### Chicken Thigh Sample Procurement

Bone-in broiler thighs, with the skin on and no prior antimicrobial treatment (0.25–0.30 kg per thigh), were obtained from a commercial poultry processing plant within 24 h of harvest and stored at 2°C on 3 separate occasions. For each treatment, 2 thighs were placed in a package (VAK*3.0 R, Winpak, Winnipeg, CA) and randomly assigned storage times of 0, 4, 8, 12, 16, and 20 d.

### Treatments

Treatments consisted of 1.0% vinegar, 0.5% vinegar, a positive control, and a negative control. For the 1.0% vinegar treatment, 5 mL of vinegar [e(Lm)inate V, Hawkins Inc., Minneapolis, MN] was sprayed into the bag (Winpak VAK*3.0 R, oxygen transmission 24 h/23°C Dry-63 cm³/m² and Moisture Vapor Transmission 24 h/37.8°C at 90% RH, 4.8 g/m²) on the thighs (500 ± 20 g) and mixed on the surface through pulling a vacuum before filling the bag with CO₂. The CO₂ gas packaging was done using a Turbovac ST-320 (HFE Vacuum Systems, Hertogenbosch, the Netherlands), vacuum packager. For the 0.5% vinegar treatment, 2.5 mL of vinegar was sprayed on the thigh samples. The positive control was sprayed with 5 mL of deionized/distilled water in the place of vinegar, and the negative control group was not sprayed with vinegar or water.

After treatment, each bag was filled with approximately 100% CO₂ (verified using a gas analyzer) so that the bag volume was filled to 50% capacity (to minimize headspace) and then stored at 2 to 4°C in a walk-in cooler. After 6 d of storage, color and pH were evaluated, and trained panelists (n = 6–8) evaluated the flavor of cooked thigh meat (170°F) using a difference from control test. In addition, mesophilic and lactic acid bacteria were enumerated after 0, 4, 8, 12, 16, and 20 d of storage.

#### pH Measurement

The pH of the chicken thigh samples was measured using a pH meter (model Accumet 61, Fisher Scientific, Hampton, NH) with an attached meat penetrating probe (penetration tip, Cole Palmer, Vernon Hills, IL), which was inserted directly into the chicken thigh muscle at 3 different locations. Two chicken thighs were used for each treatment per replication (Kin et al., 2009, 2010).

#### Instrumental Color Evaluation

Instrumental color was determined using a chroma meter (model CR-400, Minolta Camera Co Ltd., Osaka, Japan) with an 8-mm port size, 2° observer, and illuminant D65. Calibration of the instrument was carried out using a standard white Minolta calibration plate (model no. 20933026). Color of chicken thighs (negative control and 0.5%, 1.0% sprayed vinegar treatment) were measured and expressed as CIE L* (lightness), a* (redness), and b* (yellowness). For each chicken thigh sample, color was determined at 3 different locations (2 thighs for each treatment per replication) and averaged before statistical analysis.

#### Microbial Enumeration

The mesophilic and lactic acid bacteria counts were enumerated after 0, 4, 8, 12, 16, and 20 d of storage at 2°C. Bacto peptone water (0.1%, Remel, Thermo Fisher Scientific, Hampton, NH) containing 0.02% Tween-80 was used as an extraction medium. Peptone water was added to chicken thigh samples in a 1:1 ratio, and samples were hand massaged for 2 min. Homogenates were plated on aerobic plate count petrifilms for mesophilic plate counts (room temperature incubation for 3 d) and de Man, Rogosa and Sharpe agar (Thermo Scientific Remel MRS Agar, Hampton, NH) for *Lactobacillus* count at 37°C for 3 d under anaerobic condition.

<table>
<thead>
<tr>
<th>Item</th>
<th>pH</th>
<th>CIE L* chicken skin</th>
<th>CIE a* chicken skin</th>
<th>CIE b* chicken skin</th>
<th>CIE L* thigh meat</th>
<th>CIE a* thigh meat</th>
<th>CIE b* thigh meat</th>
<th>Difference from control score²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Treatment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive control</td>
<td>NA³</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Negative control</td>
<td>6.11</td>
<td>75.7</td>
<td>0.84</td>
<td>9.3</td>
<td>54.0</td>
<td>3.9</td>
<td>5.1</td>
<td>0.90</td>
</tr>
<tr>
<td>0.5% vinegar</td>
<td>6.07</td>
<td>76.0</td>
<td>0.71</td>
<td>9.4</td>
<td>54.0</td>
<td>3.6</td>
<td>4.9</td>
<td>0.95</td>
</tr>
<tr>
<td>1.0% vinegar</td>
<td>6.15</td>
<td>76.1</td>
<td>−0.20</td>
<td>11.1</td>
<td>55.3</td>
<td>3.1</td>
<td>5.1</td>
<td>0.90</td>
</tr>
<tr>
<td>Pooled SEM</td>
<td>0.023</td>
<td>0.25</td>
<td>0.35</td>
<td>0.72</td>
<td>0.42</td>
<td>0.32</td>
<td>0.33</td>
<td>0.11</td>
</tr>
<tr>
<td>²P-value</td>
<td>0.36</td>
<td>0.77</td>
<td>0.43</td>
<td>0.52</td>
<td>0.44</td>
<td>0.58</td>
<td>0.96</td>
<td>0.97</td>
</tr>
</tbody>
</table>

¹Raw color of chicken skin [Commission Internationale d’Eclairage (CIE) L* (lightness) = 0 to 100; CIE a* (redness) = −60 to 60; CIE b* (yellowness) = −60 to 60].

²Difference from control scale: 0 = no difference; 1 = slight difference; 2 = moderate difference; 3 = large difference; 4 = very large difference. The negative control was both the control and blind control sample in the test.

³NA = not applicable.
**Sensory Evaluation**

The difference from control test was conducted according to Desai et al. (2012) with slight modifications. The panelists who participated in the difference from control sensory testing of chicken thighs have more than 100 h of experience in muscle food sensory evaluation and training on beef, pork, poultry, and catfish products between 2010 and 2013. Prior to sensory testing, the chicken thigh treatments (1.0% vinegar, 0.5% vinegar sprayed, and negative control) were assigned 3-digit random codes. The blind control was the negative control, but its identity was hidden from the panelists because it was assigned a random 3-digit number along with the other 2 treatments and served to the panelists during the difference from control test. The blind control serves as an anchor to ensure that differences between samples and the control are greater than differences between the control and the identical blind control. Panelists evaluated the flavor of cooked chicken thigh samples on a 0- to 4-point scale (0 = no difference, 1 = slight difference, 2 = moderate difference, 3 = large difference, 4 = very large difference). In addition, 2 members of the trained sensory panel sniffed the aroma coming from the package 30 s after the bag was opened and evaluated the aroma. This was an objective measurement to determine if there was any vinegar aroma or spoilage.

**Statistical Analysis**

A randomized complete block design (replications as blocks) with 3 replications was used to test the effect of vinegar ($P < 0.05$) on pH, color, and sensory differences (SAS version 9.2, SAS Institute Inc., Cary, NC). A randomized complete block design with a factorial structure was used to determine differences in mesophilic and lactic acid bacteria counts over storage time. When significant differences occurred ($P < 0.05$) among treatments, the Duncan’s multiple range test was used to separate treatment means.

![Total Mesophilic Microbial Load](image)

**Figure 1.** Total mesophilic microbial load of chicken thighs that were treated with 0, 0.5, or 1.0% vinegar before packaging in CO2 and stored (2–4°C) for up to 20 d. C = control with 1.0% deionized water; NC = negative control; V0.5 = 0.5% vinegar; V1.0 = 1.0% vinegar. Means with different letters (a–c) within each storage time are different ($P < 0.05$).
RESULTS AND DISCUSSION

No differences existed \((P > 0.05)\) among treatments with respect to pH, skin CIE L* a* b* (lightness, redness, yellowness), and meat color (lightness, redness, yellowness; Table 1). This indicates that spraying chicken thigh retail cuts with up to 1.0% buffered vinegar does not affect the pH and color of the chicken skin or meat when it is packaged in carbon dioxide. In addition, there was no sensory difference detected \((P > 0.05)\) between the control and vinegar-treated samples (Table 1). The sensory difference from control scores indicated that the trained panelists could not detect any flavor difference between the control and vinegar-treated cooked chicken thigh samples (Table 1). A sniffing test was also conducted on the control and vinegar-treated chicken thigh samples. Immediately after opening the packages, there was a slight vinegar aroma in the bag for the 0.5 to 1.0% vinegar samples on day 0, 4, and 8, but the aroma dissipated quickly. The vinegar aroma was also not detected without sniffing directly into the bag, and the aroma of the 1.0% vinegar samples at day 16 and 20 had no spoiled odor, but the control samples on day 16 and 20 smelled spoiled due to bacterial growth (data not shown). Crist et al. (2012) showed that the combination of acetic acid (2.5%) and sodium lactate (2.5%) can be useful in extending the shelf life of fresh Italian pork sausage links for up to 18 d of storage without negatively influencing the sensory qualities.

No differences existed \((P > 0.05)\) in mesophilic and lactic acid bacteria counts after 0 and 4 d of storage. However, the mesophilic bacterial load was less \((P < 0.05)\) in the 1.0% vinegar treatment compared with other treatments after 8, 12, 16, and 20 d of storage (Figure 1). In addition, the control samples were approaching spoilage at 12 d and had a very spoiled aroma by d 16, whereas the 1.0% vinegar treatment was not approaching spoilage until 20 d, which indicates that the microbial shelf life of the broiler thighs were extended from approximately 12 to 20 d. Previous research has indicated that fresh poultry meat products with total viable counts between \(10^7\) to \(10^8\) cfu/g are considered to have reached the end of their shelf life (Senter et al., 2000). In the present study, the mesophilic counts reached approximately \(10^6\) cfu/g at d 12 and \(10^8\) cfu/g at d 16. In addition, the 0.5% vinegar treatment had lower bacterial counts at d 12 than both controls and had an approximate shelf life of 16 d (Figure

![Lactobacillus Counts from MRS Agar Plates](image)

**Figure 2.** Lactic acid bacterial counts of chicken thighs that were treated with 0, 0.5, or 1.0% vinegar before packaging in CO\(_2\) and stored (2–4°C) for up to 20 d. C = control with 1.0% dionized water; NC = negative control; V0.5 = 0.5% vinegar; V1.0 = 1.0% vinegar. Means with different letters (a,b) within each storage time are different \((P < 0.05)\). MRS = de Man, Rogosa, and Sharpe.
of other synergistic antimicrobials with CO2 packaging to approximately 20 d. In future work, a combination cause shelf life can be extended from approximately 12 when broiler retail cuts are shipped long distances be-
hore customers when broiler retail cuts are shipped long distances because shelf life can be extended from approximately 12 d to approximately 20 d. In future work, a combination of other synergistic antimicrobials with CO2 packaging to increase the shelf life of broiler retail cuts needs to be evaluated.

ACKNOWLEDGMENTS

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REFERENCES


