The effect of sodium lactate and lactic acid combinations on the microbial, sensory, and chemical attributes of marinated chicken thigh

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ABSTRACT The present study was undertaken to evaluate the chemical, microbiological, and sensory effects of different sodium lactate (SL) and lactic acid (LA) combinations on marinated chicken thigh. The latter were treated with SL and LA combined at various concentrations, namely 0.3 and 0.03; 0.5 and 0.05; 0.6 and 0.06; 0.75 and 0.075; and 0.9 and 0.09%, respectively. The findings indicated that those combinations were efficient (P < 0.05) against the proliferation of various spoilage microorganisms, including aerobic plate count, psychrotrophic populations, Pseudomonas spp., Staphylococcus aureus, Enterobacteriaceae, and Salmonella spp. The results from chemical analyses revealed that the treated thigh underwent significant decreases (P < 0.05) in terms of pH values and total volatile base nitrogen contents. Significant differences (P < 0.05) were, however, detected with regard to their sensory attributes, with SL-LA concentrations of 0.9 and 0.09 yielding the highest scores for the color, texture, and flavor attributes. Overall, the findings demonstrated that the addition of 0.9% SL and 0.09% LA to marinated chicken can help delay the proliferation of spoilage microorganisms, prevent the generation of undesirable chemicals, improve the levels of sensory attributes, and extend the shelf life of products during refrigerated storage.

Key words: marinated chicken, sodium lactate, lactic acid, microbiological effect, sensory attribute

INTRODUCTION

The marketing of marinated poultry products is increasingly becoming one of the prominent segments in the global food industry due to the promising opportunities that marination has opened with regard to extending the versatility of processed product (Guerreiro-Legarreta and Hui, 2010). The term marinades, or marinated poultry products, is used to define complex water-oil emulsions typically containing combinations of sugar, salt, weak acids (such as acetic, citric, and lactic acids), additives (xanthan and guar gum), spices, sorbates, benzoates, and aroma enhancers (Björkroth, 2005). Marination is used for various purposes, such as the improvement of microbiological and technological quality and the extension of shelf life. Technological qualities relate to evaluated attributes that characterize meat quality, namely color, water-holding capacity, processing ability, texture, and tenderness (Allen et al., 1998; Fernandez et al., 2002).

Several techniques have been used for applying marinades to poultry meat. Two preservative agents, namely sodium lactate (SL) and lactic acid (LA), have attracted special attention in the literature. Various studies have focused on the application of SL either alone (Carroll et al., 2007) or in combination with sodium diacetate, potassium lactate, potassium diacetate (Alavarado and McKee, 2007), or acetic acid (Bradley et al., 2011). Other studies focused on the use of LA either alone (Djenane et al., 2003) or in combination with trisodium phosphate (del Río et al., 2006), lauricidin (Anang et al., 2010), or acetic acid (Kotula and Thelappurate, 1994) solutions. So far, and to the authors’ knowledge, the combination between SL and LA was investigated only in one study by Zeitoun and Debevere (1992). It investigated the effect of various SL and LA concentrations together with modified atmosphere packaging on the shelf life and organoleptic quality of chicken legs.

Several fish, meat, and poultry products have been marinated using various concentrations of SL. Several works focused on the application of SL at concentrations of up to 5% (De Wit and Rombouts, 1990; Stekelenburg and Kant-Muermans, 2001). The sodium components were shown to enhance the quality as well as sensory taste and flavor of the meat (Carroll et al., 2007).
Several organic acids, such as acetic, formic, and lactic acids, have previously been reported to improve shelf lives by decreasing the microbial loads of meat products (Osthold et al., 1984; Smulders and Wootthius, 1985). In fact, high levels of LA were demonstrated to inhibit or inactivate Listeria monocytogenes, even at neutral pH. Several studies concluded that the inactivation rate depends not only on the environmental pH but also on the type and concentration of the acid used (Guerrero-Legarreta and Hui, 2010). Furthermore, the use of organic acids in meat systems has been shown to increase the collagen solubility (Oreskovich et al., 1992), reduce the shear force, and improve the sensory taste (Sawyer et al., 2008) values of meat and poultry products.

The chickens (Gallus domesticus) used in this study were obtained from a local poultry farm in Sfax, Tunisia. They were 38 d old and had a live weight of 1.2 ± 0.2 kg. The animals were electrically stunned (11 mV, 10 s), manually slaughtered (severed left carotid artery and jugular vein), bled out (2–5 min), scalded (55°C, 2–5 min), and picked in-line using commercial defeathering equipment. The carcasses were manually eviscerated and placed in a prechill tank for 15 min at 12°C, and then in a chill tank for 40 min at 1°C. The carcasses were manually agitated at regular intervals throughout the chilling process to reduce thermal layering around the carcasses and improve chilling efficiency. Finally, the thighs were manually deboned, separated, and stored until further use. The samples (n = 24), having an average weight of 50 ± 10 g, were transferred to the Laboratory of Enzymes and Bioconversion at the National School of Engineering of Sfax, Tunisia, 1 h after slaughtering. They were packaged in closed plastic bags (quart size #487435, Ziploc Brand bags, S. C. Johnson and Son Inc., Racine, WI) and stored in a 4°C cooler. They were later divided into 2 groups, namely marinated and unmarinated (control) groups.

### MATERIALS AND METHODS

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### Chemical Analyses

#### pH

Ten grams of muscle was homogenized in 50 mL of distilled water. The pH was measured, on individual raw fillets and after marinating at 20°C, using an MP 220 pH meter (Mettler-Toledo GmbH, Schwerzenbach, Switzerland).

#### Total Volatile Bases Nitrogen

To determine total volatile bases nitrogen (TVBN), 10 g of each sample was homogenized in 50 mL of distilled water. The solution was prepared 1 d before application and stored at 4°C. It was formulated based on percentage of meat weight. The marination yield was calculated using the following equation:

\[
\% \text{ marination yield} = \frac{\text{marinated weight} - \text{raw weight}}{\text{raw weight}} \times 100
\]

### Chemical Composition of the Chicken Meat

The moisture content of the samples was determined by air drying in an air oven in accordance with the AOAC method 950.46 (AOAC, 2000). The protein content was determined using the Kjeldahl nitrogen method described in the AOAC method 928.08 (AOAC, 2000). The total crude fat content was estimated using the ether extraction technique described in the AOAC method 954.02 (AOAC, 2000).

### Influence of Additives on Marinades

To study the effect of additives on marinated poultry meat, different combinations using SL and LA at various concentrations were prepared and stored at 4°C. In particular, the present study investigated the following combinations: 0.3 and 0.03, 0.5 and 0.05, 0.6 and 0.06, 0.75 and 0.075, and 0.9 and 0.09%, respectively.

### Marination Process

The experimental design consisted of 2 parts. One part of chicken thigh meat was used as a control (non-marinated) n = 12. The other part was weighed, individually identified (n = 12), and then rotated every 20 min in a vacuum tumbling (LT5 Koch Tumbler, Lance Industries, Allenton, WI; 20% wt/wt marinade addition, 45.7 cm, 1 h, 14 rpm, 4°C) to ensure even marination. The proportion between the meat and the marinade was fixed at 1:2. The control and marinated samples were then enclosed in sealed plastic pouches and stored in a refrigerator either for 15 d, followed by submission to chemical and microbiological analyses, or overnight, followed by subjecting to a cooking process. The cooked samples would be used only for sensory evaluation.

### Marinate

The marinate formulation consisted of water, salt, spices, oils, and lemon. The solution was prepared 1 d before application and stored at 4°C. It was formulated based on percentage of meat weight. The marination yield was calculated using the following equation:
was mixed with 100 mL of distilled water. An amount of 2 g of magnesium oxide and an antifoaming agent were then added to the mixture. The latter was then distilled using a micro-Kjeldahl distillation apparatus. The distillate was collected for 25 min into 25 mL of 4% boric acid with 5 drops of Tashoro indicator. The solution was titrated using 0.1 M HCl to calculate the total VBN in terms of mg of VBN/100 g (Pearson, 1976).

**Microbiological Analysis**

Ten grams of the chicken thigh sample was placed into a sterile stomacher bag and added to 90 mL of peptone (0.1%) and NaCl (0.8%). The pH was adjusted to 7.2, and the mixture was then macerated for 2 min. One milliliter of the homogenate was serially diluted in aseptic conditions and used for the enumeration of microorganisms (AFNOR, 2004).

**Aerobic Plate Count.** Aerobic plate counts (APC) were determined by inoculating 0.1 mL of the sample homogenate onto triplicate sterile plates of prepared and dried standard methods agar using the surface spread technique. The plates were then incubated for 48 h at 35°C (APHA, 1992). The standard methods agar is a standardized medium for the enumeration of microorganisms from materials of sanitary importance. It was performed in accordance with the American Public Health Association formulation for plate count agar. It is based on the principle that enzymatic digest of casein provides the amino acids and other complex nitrogenous substances necessary to support bacterial growth (Wehr and Frank, 2004).

Duplicates of each dilution (1 mL) of neutralized and nonneutralized samples were pour-plated using standard methods agar (Oxoid, Basingstoke, Hampshire, UK) and incubated at 30 ± 1°C for 48 ± 3 h. Plates containing 25 to 250 colonies were selected and counted, and the average number of cfu/mL was calculated.

**Psychrotrophic Count.** Psychrotrophic counts (PTC) were determined as described above for APC except that plates were incubated at 7°C for 10 d (Cousin et al., 1992).

**Pseudomonas Count.** Pseudomonas were enumerated on Pseudomonas agar base (CM 559, Oxoid) supplemented with cetrimide, fucidin, and cephaloridine, providing a selective isolation medium for *Pseudomonas* spp. Colonies were counted after 2 d of incubation at 25°C (Mead and Adams, 1977).

**Enterobacteriaceae Count.** Enterobacteriaceae is a family of microbes that colonize the gastrointestinal tract of mammals. *Enterobacteriaceae* counts were determined by the pour-plating technique in violet red bile glucose agar. The plates were overlaid with a virgin layer of the same growth medium before incubation at 37°C for 24 h. It is worth noting in this context that *Enterobacteriaceae* is a large family of bacteria that includes several enteric pathogens, such as *Salmonella*.

**Salmonella.** Chicken thighs were sampled aseptically by excising surface areas of 25 cm². A sterile filter paper (5 × 5 cm) was used to outline the area. Filter paper and skin were homogenized for 2 min in 250 mL of sterile buffered peptone water (Oxoid CM 509) incubated at 37°C for 24 h. After incubation, 1 mL of each enrichment culture was transferred to 10 mL of tetrathionate broth (Oxoid CM 29) and incubated at 42°C for 24 h (Al-Rajab et al., 1986).

These enrichment cultures were streaked on xylose lysine desoxycholate (Oxoid CM469) and on brilliant green agar (Oxoid CM329). The plates were incubated at 35°C for 24 h. Red Colonies with black centers on xylose lysine desoxycholate and red colonies surrounded by bright red on brilliant green agar were picked off the plates and subcultured to triple sugar from agar (Merck No. 3915), lysine decarboxylase broth (Oxoid CM 308), and urea agar base (Oxoid CM53). The slants were incubated at 35°C for 24 h (Al-Rajab et al., 1986). Microbiological data were transformed into logarithms of the number of colony-forming units (cfu/25 g).

**Staphylococcus aureus.** Surviving population of *Staphylococcus aureus* was determined by standard plating methods (Lindsay and Von Holy, 1999). At each sampling time, colonies of *Staphylococcus* were selected, Gram stained, and observed for catalase and oxidase reactions to confirm the presence of *Staphylococcus aureus* (Ingham et al., 2006). Microbiological data were transformed into logarithms of the number of colony-forming units (cfu/g).

**Sensory Evaluation**

**Cooking.** Marinated samples were subsequently dried and cooked at 170°C in a Zanussi convection oven (C. Batassi, Conegliano, Italy) for approximately 15 min to reach an internal temperature of 75°C, as measured by an internal temperature probe (Testo 110, Lenzkirch, Germany). All test samples were cooked at the same time and segregated to prevent any mixing. Chicken thighs were cooked in an area separated from the testing one. Thigh pieces were kept warm in an oven at 40 ± 5°C until later served to panellists. The holding period did not exceed 1 h after cooking.

**Cooking Loss Determination.** All cooked samples were dried and, again, weighed individually. Cooking loss was expressed as g/100 g by weight difference between uncooked and cooked samples. Cooking loss was then calculated as the average value (n = 3) + SE (Barbanti and Pasquini, 2005).

**Sensory Attributes.** The sensory attributes were evaluated by a panel of 96 people. Each person had to assess levels of color (golden brown or pale), aroma, texture (toughness or juiciness), and flavor (sourness or sweetness). Thigh samples of 1 to 1.25 cm² from the different treatments were individually presented in covered small porcelain dishes to each panelist in a separate area where distracters, noises, and odors were minimized. The judges were not informed about the experimental approach and the samples were blind-coded with 3-digit random numbers. A 9-point hedonic scale
(9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, 1 = dislike extremely) was used for the evaluation of the overall acceptability.

### Statistical Analysis

A $6 \times 3 \times 3 \times 6$ completely randomized experimental design was used; it consisted of 6 treatments (5 combinations + control), 3 pieces of meat, 3 replications, and 6 storage times.

On each sampling occasion, 3 independent samples from each processing condition were submitted to microbial, sensory, and pH analyses. All measurements were carried out in triplicates, and all microbial counts were converted into base-10 logarithms of colony-forming units per gram of thigh samples ($\log_{10}$ cfu/g). The data were subjected to ANOVA using the GLM procedure of the Statistical Analysis System software of the SAS Institute (SAS Institute Inc., 1990). Differences among the mean values of the various treatments and storage periods were determined by the least significant difference test, and significance was defined at $P < 0.05$. The differences that were equal to or more than the identified least significant difference values were considered statistically significant.

### RESULTS AND DISCUSSION

#### Chemical Composition of the Chicken Thigh

The mean percentages generated for the moisture, protein, and lipid contents of the marinated samples are shown in Table 1. The compositional analysis of nontreated thighs showed that the water content was 73.4% ± 3.4, the protein content was 19.2% ± 1.6, and the lipid content was 6.8% ± 0.4. This analysis also showed that there were slightly significant differences ($P < 0.05$) in proximate composition after the marination process. In fact, while the water content was noted to decrease, the lipid and protein contents were observed to undergo slight increases ($P < 0.05$) in the different treatments (Table 1).

#### Chemical Quality

The literature presents several chemical methods for the establishment of quality deterioration indices of chicken thigh during storage at 4°C. Chemical tests have particularly been employed to measure the amounts of breakdown products resulting from enzymatic, bacterial, and oxidative activities. In the present work, the chemical quality indicators used to determine the chemical changes in marinated chicken thigh consisted of pH values and TVBN contents.

### Changes in pH Value

The data presented in Table 2 indicate the pH evolution in chicken thighs treated with 5 different SL and LA combinations. The initial pH recorded for the control and the treated samples was above 6.0. The findings revealed that the marination process brought about a decrease in terms of the initial pH of the marinades, which became 5.81 with 0.9% SL and 0.09% LA, compared with the control (pH 6.08). Furthermore, the determination of the pH values of the samples during 15 d of treatment indicated that the pH values underwent slightly significant increases ($P < 0.05$) that reached a maximum with 0.3% SL and 0.03% LA, with the lowest pH value being obtained with 0.9% SL and 0.09% LA.

The decrease in pH values can be attributed to breakdown of the glycogen of the slaughtered animal into glucose. Glucose undergoes glycolysis but, in the absence of oxygen, lactic acid is formed, which causes the pH in the muscles to drop (Muchenje et al., 2009). Such a drop helps in the conversion of muscle to meat. According to Gonzalez-Fandos et al. (2009), the buffering capacity of the acid system seems to be sufficient to maintain a low pH in the meat. In fact, our findings are in accordance with these observations. Acidic marinades are often described to involve several functioning factors, including weakening of structures due to the swelling of meat, the increasing proteolysis by catharsis, and the increasing conversion of collagen to gelatin at low pH during cooking (Goli et al., 2011).

The tenderizing effect of organic acid on meat has often been explained through the electrostatic repulsion theory (Aktaş et al., 2003). The addition of acid below the isoelectric point of muscle protein leads to the protonation of negatively charged carboxyl groups, which results in the breakdown of several electrostatic bonds with adjacent protein chains. The increase in the net positive charge is thought to result in repulsion between protein groups of similar charge, thereby creating space for immobilization of added water (Gault, 1991).
Table 2. Effect of different combinations of sodium lactate (SL) and lactic acid (LA) on pH of chicken thigh during 15 d of storage at 4°C

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Days of storage at 4°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Control</td>
<td>6.08 ± 0.04a</td>
</tr>
<tr>
<td>0.3% SL+0.03% LA</td>
<td>6.03 ± 0.12a</td>
</tr>
<tr>
<td>0.5% SL+0.05% LA</td>
<td>5.99 ± 0.09a</td>
</tr>
<tr>
<td>0.6% SL+0.06% LA</td>
<td>5.91 ± 0.13a</td>
</tr>
<tr>
<td>0.75% SL + 0.075% LA</td>
<td>5.88 ± 0.04a</td>
</tr>
<tr>
<td>0.9% SL+0.09% LA</td>
<td>5.81 ± 0.05a</td>
</tr>
</tbody>
</table>

a–dAverages with different letters in the same column are different (P < 0.05).

A clear correspondence was found between the microbiological quality of fresh chicken and the level of metabolites. Total volatile bases nitrogen formation took place evenly during the storage period; its formation was, however, dependent upon temperature (Balamatsia et al., 2007). For the samples with added preservatives, the maximal allowed levels of TVBN were attained at the ninth, thirteenth, and sixteenth days for the combinations 0.3% SL and 0.03% LA, 0.6% SL and 0.06% LA, and 0.9% SL and 0.09% LA, respectively (Figure 1). These results indicated the significant effect (P < 0.05) of the SL and LA combinations in the reduction of chemical changes in marinated chicken.

**Microbiological Evaluation**

**APC.** The increase in storage time resulted in significant proliferations (P < 0.05) in APC, regardless of the type of treatment being applied (Table 3). The

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**Figure 1.** Changes in the total volatile bases nitrogen (TVBN) content in marinated chicken thighs treated with different combinations of sodium lactate (SL) and lactic acid (LA) stored at 4°C (P < 0.05). Control (■), 0.3% SL + 0.03% LA (▲), 0.6% SL + 0.06% LA (♦), and 0.9% SL + 0.09% LA (●).
log mean count recorded for the APC of the control chicken meat samples on d 0 was 3.83 log$_{10}$ cfu/g. On d 6 of storage, their log mean count of APC reached 6.86, which was close to the maximum limit of 7 log$_{10}$ cfu/g for APC recommended by ICMSF (1986) in processed chicken. On d 9 of storage, the APC of the control chicken meat samples increased to 7.52 log$_{10}$ cfu/g, and signs of spoilage started to appear as a slight foul smell, which indicated a shelf life of 5 to 6 d.

The APC values recorded for the chicken meat samples that were marinated with SL and LA combinations were, on the other hand, noted to show delayed growth when compared with the controls. On d 12 of storage, for example, the chicken thighs treated with 0.3% SL and 0.03% LA exhibited a delayed growth in terms of APC to about 2.4 log$_{10}$ cfu/g, thus extending shelf life to up to 14 d during storage at 4°C (Table 3).

**PTC and Pseudomonas Count.** The gram-negative genus Pseudomonas spp. is often reported to be the most vulnerable group to LA treatment (Gerez et al., 2009). The initial PTC recorded for the samples treated with SL and LA combinations was noted to range between 2.81 and 3.03 log$_{10}$ cfu/g, whereas their initial Pseudomonas counts ranged between 1.24 and 1.72 log$_{10}$ cfu/g (Table 3). These counts were lower than the ones recorded for the controls and were noted to decrease with the increase in the percentage of the preservative in the marinated thighs. Moreover, during the storage time, while the PTC and Pseudomonas counts were noted to increase, all treatments were observed to result in significant reductions in those populations ($P < 0.05$) in chickens thighs. In fact, whereas the PTC and Pseudomonas populations registered for all treated samples during the 15-d period of storage did by no means reach 7 and 6 log$_{10}$ cfu/g, respectively, 12 d of storage were sufficient for the control samples to attain these rates (Table 3).

<table>
<thead>
<tr>
<th>Item</th>
<th>Days of storage at 4°C</th>
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<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td><strong>APC</strong></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
</tr>
<tr>
<td>0.3% SL+0.03% LA</td>
<td>0.3</td>
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<tr>
<td>0.5% SL+0.05% LA</td>
<td>0.5</td>
</tr>
<tr>
<td>0.75% SL+0.075% LA</td>
<td>0.75</td>
</tr>
<tr>
<td>0.9% SL+0.09% LA</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>PTC</strong></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
</tr>
<tr>
<td>0.3% SL+0.03% LA</td>
<td>0.3</td>
</tr>
<tr>
<td>0.5% SL+0.05% LA</td>
<td>0.5</td>
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<tr>
<td>0.75% SL+0.075% LA</td>
<td>0.75</td>
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<tr>
<td>0.9% SL+0.09% LA</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Pseudomonas count</strong></td>
<td></td>
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<tr>
<td>Control</td>
<td></td>
</tr>
<tr>
<td>0.3% SL+0.03% LA</td>
<td>0.3</td>
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<tr>
<td>0.5% SL+0.05% LA</td>
<td>0.5</td>
</tr>
<tr>
<td>0.75% SL+0.075% LA</td>
<td>0.75</td>
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<tr>
<td>0.9% SL+0.09% LA</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Enterobacteriaceae count</strong></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
</tr>
<tr>
<td>0.3% SL+0.03% LA</td>
<td>0.3</td>
</tr>
<tr>
<td>0.5% SL+0.05% LA</td>
<td>0.5</td>
</tr>
<tr>
<td>0.75% SL+0.075% LA</td>
<td>0.75</td>
</tr>
<tr>
<td>0.9% SL+0.09% LA</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>Staphylococcus aureus count</strong></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
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</tbody>
</table>

a–cAverages for different microbial analyses with different letters in the same column are different ($P < 0.05$).

*Data are given as ± SD of 3 replicates.
the other hand, observed to display reduction rates of about 0.49 and 1.38 log10, respectively. These results indicated that the combination 0.9% SL and 0.09% LA significantly \((P < 0.05)\) reduced PTC and 

**Enterobacteriaceae Counts.** The initial Enterobacteriaceae counts recorded for the control samples were about 1.41 log10 cfu/g and were noted to remain below the detection limit for the treated samples. The counts made for these pathogens underwent slight increases \((P < 0.05)\) during the storage period with the different combinations being tested. By the end of the storage period, however, and compared with the ones recorded for the untreated group, all the Enterobacteriaceae counts registered for the samples treated with the different SL and LA combinations were noted to decrease \((P < 0.05)\) (Table 3). Interestingly, the Enterobacteriaceae counts recorded for the 0.9% SL/0.09% LA combination were noted to remain under the detection limits until d 15 of storage, which clearly demonstrated that this latter treatment brought about a significant \((P < 0.05)\) reduction in terms of the Enterobacteriaceae counts in marinated chicken. Furthermore, the results from the Salmonella detection test were negative, thus confirming that all the treated samples met the conventional standards specified, with regard to fitness for human consumption (APHA, 1992).

**Staphylococcus aureus Count.** Staphylococcus aureus has often been tested in poultry products to assess microbiological safety, sanitation conditions, and product quality during processing and storage (Tompkin, 1983). The presence of Staphylococcus aureus could occur due to inappropriate techniques applied, with regard to personal hygiene, abdomen opening, hand deboning, or hand washing.

Despite the presence of Staphylococcus aureus in the chicken thigh samples, the levels of this pathogen were noted to remain under the standard limit. In fact, the initial Staphylococcus aureus counts recorded for all treatments were below the detection limit. By the end of d 15, the marinated chicken thighs treated with the different SL and LA combinations revealed significant decreases \((P < 0.05)\) in terms of Staphylococcus aureus counts as compared with the control samples (Table 3). In fact, all counts measured for both combinations 0.75% SL/0.075% LA and 0.9% SL/0.09% LA were under the detection threshold. In this context, the inhibitory action of LA on bacteria has been attributed mainly to reduction in environmental pH (Koutsoumanis et al., 2006). This result is in agreement with the findings presented in the current work because, compared with the other samples, the samples treated with 0.9% SL and 0.09% LA showed lower pH and marked decrease in microorganism counts. Sawyer et al. (2008) reported that LA improves shelf life by decreasing microbial loads on meat products. Several studies focused on the effect of sodium lactate on the bacterial growth of other species. It was, for instance, shown to have an antimicrobial effect on Lactobacillus curvatus and Listeria monocytogenes (Steekenburg and Kant-Muermans, 2001). This antimicrobial effect was also investigated on various lactic acid bacteria, Staphylococcus aureus, Salmonella Typhimurium (De Wit and Rombouts, 1990), and Clostridium perfringens (Juneja, 2006).

The findings from the microbiological analyses reported in this study indicated that the best combination that delayed or inhibited antimicrobial activity was 0.9% SL and 0.09% LA.

### Sensory Evaluation

Sensory evaluation is the most popular way of assessing the freshness of marinated chicken. It provides simple, fast, and immediate information on product quality. The color, texture, and flavor attributes of the marinated chicken thigh samples treated with the different combinations assayed in the present work are shown in Table 4.

Significant differences \((P < 0.05)\) were detected between the overall acceptability scores obtained for the treated marinated samples. The sensory scores gathered for all the samples treated with SL and LA were in the typical categories of color, texture, and flavor and no off-odor or off-flavor detected. Interestingly, however, the results indicated that samples treated with 0.9% SL and 0.09% LA showed the highest overall acceptability score \((8.1 \pm 0.17)\), followed by the samples marinated with the combination 0.75% SL/0.075% LA.

### Table 4. Effect of control and different combinations of sodium lactate (SL) and lactic acid (LA) on sensory attributes of marinated chicken thigh

<table>
<thead>
<tr>
<th>Sensory attribute</th>
<th>Control 0.3% SL+ 0.03% LA</th>
<th>0.5% SL+ 0.05% LA</th>
<th>0.6% SL+ 0.06% LA</th>
<th>0.75% SL+ 0.075% LA</th>
<th>0.9% SL+ 0.09% LA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>5.2 ± 0.17&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.5 ± 0.14&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.6 ± 0.16&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.0 ± 0.16&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.5 ± 0.15&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Texture</td>
<td>5.6 ± 0.16&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.8 ± 0.18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.9 ± 0.14&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.0 ± 0.13&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7.1 ± 0.10&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Flavor</td>
<td>7.1 ± 0.15&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.1 ± 0.19&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.2 ± 0.10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.2 ± 0.11&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.3 ± 0.13&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Overall acceptability</td>
<td>6.4 ± 0.12&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.7 ± 0.10&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>6.8 ± 0.15&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>6.9 ± 0.19&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.4 ± 0.12&lt;sup&gt;bc&lt;/sup&gt;</td>
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<sup>a</sup> Different letters in the same row, for each parameter, are different \((P < 0.05)\).

<sup>1</sup>Data given as ± SD of 3 replicates.
that showed an overall acceptability of 7.4 ± 0.12. A significant difference ($P < 0.05$) was detected, for the overall acceptability, between the marinated samples. Moreover, all of the samples analyzed were considered as acceptable during sensory analysis. Bacterial populations as well as chemical indicators (pH and TVBN) coincided with the sensory scores.

A comparative study was previously conducted on the sensory characteristics of cooked chicken thighs washed with different concentrations of trisodium phosphate (Capita et al., 2000). The study reported on the use of a 9-point hedonic scale that aimed to test the effect of trisodium phosphate solutions washing on the color, smell, texture, flavor, and overall acceptability of poultry thigh. The control samples used in the mentioned study had better initial attributes than the ones used in the present work (color, texture, and overall acceptability). Capita et al. (2000) reported that after treatments with trisodium phosphate at different concentrations, the texture taste was improved but the color, flavor, and overall acceptability attributes were noted to decrease. The findings of the present work, on the other hand, indicated that all the sensory characteristics were improved. This strongly suggests that the use of SL and LA combinations in marinate is more effective and appropriate for industrial application than the washing with trisodium phosphate solution.

Overall, the present study showed that treatment with LA and SL combinations can delay the microbial growth, reduce the chemical changes, and improve or maintain the sensory attributes of marinated chicken meat. Better results were attained with combined concentrations of 0.9% SL and 0.09% LA, which allowed for the extension of shelf life during refrigerated storage. Marination with LA and SL can, therefore, be considered as a strong and promising candidate for future application as a safe method for the preservation of poultry products.

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REFERENCES


