

Research Article

The Effect of Marinade Containing Lactic Acid Bacteria on the Microbial Quality and Shelf Life of Chicken Wings

Laktik Asit Bakterileri İçeren Sosun Tavuk Kanatlarının Mikrobiyal Kalitesi ve Raf Ömrü Üzerindeki Etkisi

Enise Begüm GÖÇMEZ¹, Osman İrfan İLHAK²

¹Department of Food Processing, Kiraz Vocational School, Dokuz Eylül University, İzmir, Türkiye

²Department of Food Hygiene and Technology, Faculty of Veterinary Medicine, Balıkesir University, Balıkesir, Türkiye

Corresponding Author:

Enise Begüm GÖÇMEZ

✉enisebegum.gocmez@deu.edu.tr

ORCID:

EBG: 0000-0001-7364-506X

Oİİ: 0000-0002-1769-6249

Received: 23.02.2026

Accepted: 27.04.2026

Published: 15.06.2026

Citation:

Göçmez EB, İlhak Oİ. The Effect of Marinade Containing Lactic Acid Bacteria on the Microbial Quality and Shelf Life of Chicken Wings. Kocatepe Veterinary Journal (2026) 19(2):91-102

Submitted for possible open access publication under the terms and conditions of the [Creative Commons Attribution \(CC BY-NC 4.0\) license](https://creativecommons.org/licenses/by-nc/4.0/).



Abstract

This study evaluated the survival of *Salmonella* spp., *Listeria monocytogenes*, *Pseudomonas* spp., *Enterobacteriaceae*, total aerobic mesophilic bacteria (TAMB), lactic acid bacteria (LAB), and yeasts-molds in chicken wings marinated with a homemade sauce enriched with bioprotective lactic acid bacteria (*Lactiplantibacillus plantarum*, *Latilactobacillus sakei*, and *Latilactobacillus curvatus*) during storage at 4 °C and 8 °C. Inoculated chicken wings were divided into three groups: unmarinated control, marinated control (M), and marinated with a LAB mixture (M-LAB). Initial pH values were 6.13 for the control, 4.89 for M, and 4.97 for M-LAB. At 4 °C, *Salmonella* counts in M and M-LAB were reduced by 0.8 and 1.6 log₁₀ cfu.mL⁻¹ compared with the control, while *L. monocytogenes* counts were 2.1 and 1.3 log₁₀ cfu.mL⁻¹ lower on day 14 (p<0.05). At 8 °C, reductions in *Salmonella* and *L. monocytogenes* in marinated groups reached 1.3 and 1.8 log₁₀ cfu.mL⁻¹, respectively, compared to the control (p<0.05). *Pseudomonas* spp. exceeded the spoilage threshold of 7 log₁₀ cfu.mL⁻¹ on day 8 in the control, day 12 in M, and day 14 in M-LAB at 4 °C. *Enterobacteriaceae* counts on day 14 at 4 °C were 8.5, 6.3, and 6.2 log₁₀ cfu.mL⁻¹ in the control, M, and M-LAB groups, respectively (p<0.05). Yeast-mold counts at 4 °C on day 14 were higher in M but lower in M-LAB than in the control (p<0.05). Overall, marination with LAB effectively inhibited pathogens and spoilage microorganisms, slowed quality deterioration, improved microbial safety and shelf life of marinated chicken wings.

Keywords: Bio-Protective Cultures, Chicken Wings, *L. monocytogenes*, Marination, *Salmonella* spp.

Öz

Bu çalışma, biyokoruyucu laktik asit bakterileri (LAB) ile zenginleştirilmiş ev yapımı sosla marine edilmiş tavuk kanatlarında *Salmonella* spp., *Listeria monocytogenes*, *Pseudomonas* spp., *Enterobacteriaceae*, toplam aerobik mezofilik bakteriler (TAMB), laktik asit bakterileri (LAB) ve maya-küflerin inhibisyon düzeyi oranları değerlendirilmiştir. Kontamine edilen tavuk kanatları üç gruba ayrıldı: marine edilmemiş kontrol, marine edilmiş kontrol (M) ve LAB karışımı ile marine edilmiş (M-LAB). Başlangıç pH değerleri kontrol için 6,13, M için 4,89 ve M-LAB için 4,97 idi. 4 °C'de, M ve M-LAB'daki *Salmonella* sayıları kontrol grubuna kıyasla 0,8 ve 1,6 log₁₀ kob/mL azalırken, *L. monocytogenes* sayıları 14. günde 2,1 ve 1,3 log₁₀ kob/mL daha düşüktü (p<0,05). 8 °C'de, marine edilmiş gruplarda *Salmonella* ve *L. monocytogenes* sayılarındaki azalma, kontrole kıyasla sırasıyla 1,3 ve 1,8 log₁₀ kob/mL'ye ulaştı (p<0,05). *Pseudomonas* spp. 4 °C'de kontrol grubunda 8. günde, M grubunda 12. günde ve M-LAB grubunda 14. günde 7 log₁₀ kob/mL'lik bozulma eşiğini aştı. 4 °C'de 14. günde *Enterobacteriaceae* sayıları kontrol, M ve M-LAB gruplarında sırasıyla 8,5, 6,3 ve 6,2 log₁₀ kob/mL idi (p<0,05). 14. günde 4°C'de maya-küf sayıları M'de daha yüksek, M-LAB'da ise kontrol grubuna göre daha düşüktü (p<0,05). Genel olarak, LAB ile marine etme, patojenleri ve bozulmaya neden olan mikroorganizmaları etkili bir şekilde inhibe etti, kalite bozulmasını yavaşlattı, marine edilmiş tavuk kanatlarının mikrobiyal güvenliğini ve raf ömrünü iyileştirdi.

Anahtar Kelimeler: Biyo-Koruyucu Kültürler, *L. monocytogenes*, Marinasyon, *Salmonella* spp., Tavuk Kanat Eti

Introduction

Chicken meat is an important source of animal protein and is widely consumed in both developed and developing countries due to its low fat content, high nutritional value, and affordability (Erdaw & Beyen, 2022; Kralik et al., 2018). Despite its popularity, poultry meat is highly perishable, and its shelf life is influenced by several factors, including processing practices, distribution, and storage conditions (Hulankova et al., 2018). Refrigeration is a primary method for slowing microbial spoilage (Ndoye et al., 2025); however, studies have shown that household refrigerator temperatures often exceed the recommended 4 °C, frequently reaching 6–8 °C or higher (Ovca et al., 2021). Such temperature deviations present a potential public health risk, particularly during warmer seasons. Among the major foodborne pathogens associated with poultry meat, *Salmonella* spp. and *Listeria monocytogenes* are of primary concern (Chen et al., 2025).

The increasing preference of consumers for foods perceived as healthy and minimally processed has led to a growing interest in alternatives to synthetic preservatives (İncili et al., 2020a; Serter et al., 2024). Within this framework, bioprotection has emerged as a promising approach to improve food safety by employing beneficial microorganisms or their bioactive metabolites (Mohammadi et al., 2022). Previous research has consistently reported that a wide range of lactic acid bacteria (LAB) possess notable antimicrobial properties against both foodborne pathogens and spoilage-related microorganisms, contributing to prolonged shelf life (Xu et al., 2023; İncili et al., 2025). The inhibitory activity of LAB is attributed to mechanisms such as microbial competition and the synthesis of antimicrobial compounds, including organic acids, hydrogen peroxide, and bacteriocins (Fan et al., 2025). Among these, *Lactiplantibacillus plantarum* is frequently applied as a biopreservative because of its ability to withstand acidic conditions and elevated salt levels (Smaoui et al., 2024). *Latilactobacillus sakei*, which is commonly associated with meat and fermented meat products, demonstrates strong adaptation to meat matrices and the capacity to grow at refrigeration temperatures. In addition, *Latilactobacillus curvatus* is recognized for its effectiveness in suppressing spoilage bacteria and for producing bacteriocins with pronounced activity against *Listeria* spp. (Kingkaew & Tanasupawat, 2023).

Although numerous studies have evaluated the use of LAB to enhance the safety and extend the shelf life of poultry products (Austriach-Comas et al., 2022; Zdolec et al., 2025; Ozturk & Sengun, 2025), research specifically examining the application of bioprotective LAB within marinades remains limited.

Accordingly, this study aimed to evaluate the impact of a LAB mixture composed of *L. plantarum*, *L. sakei*, and *L. curvatus* incorporated into a homemade marinade, on the shelf life of chicken wing meat during storage at 4 °C and 8 °C, as well as on the growth behavior of *Salmonella* spp., *L. monocytogenes*, and other microorganisms associated with spoilage.

Materials and Methods

Preparation of Lactic Acid Bacteria and Pathogenic Bacteria

Lactiplantibacillus plantarum (Bioferm DSMZ 16627), *Latilactobacillus sakei* (Bactoferm™ B-FM, Chr. Hansen GmbH, Germany), and *Latilactobacillus curvatus* (Bactoferm™ B-LC-48, Chr. Hansen GmbH, Germany), were propagated in sterile polypropylene tubes containing 10 mL of De Man, Rogosa, and Sharpe (MRS) broth (Merck, Darmstadt, Germany) and incubated at 30 °C for 18–20 h. Following incubation, bacterial cells were harvested by refrigerated centrifugation and resuspended in sterile 0.1% peptone water. The volume of each suspension was standardized to 10 mL. Plate counts on MRS agar verified that the cell concentration of each LAB culture was approximately 10⁹ cfu.mL⁻¹.

For pathogenic bacteria, three *Salmonella* strains (*S. Typhimurium* NCTC 12416, and ATCC 14028, *S. Enteritidis* ATCC 13076) and three *L. monocytogenes* strains (N7144, ATCC 13932, and 7644) were separately cultivated in Tryptone Soy Broth (Merck, Darmstadt, Germany) at a volume of 10 mL and incubated at 37 °C for

approximately 20 h. After the incubation period, the bacterial suspensions were subjected to refrigerated centrifugation, and the cell pellets obtained were subsequently resuspended in 3–4 mL of sterile 0.1% peptone water. The individual cultures of *Salmonella* were pooled to obtain a mixed inoculum, and an identical procedure was applied for *L. monocytogenes*. Each combined suspension was then brought to a final volume of 10 mL with sterile 0.1% peptone water. Viable cell counts of the pathogen mixtures were determined by serial dilution and spread plating (0.1 mL) on XLT4 agar (Merck, Darmstadt, Germany) for *Salmonella* and Oxford Listeria Selective Agar (Merck, Darmstadt, Germany) for *L. monocytogenes*. The enumeration results indicated that both pathogen cocktails contained approximately 10^8 cfu.mL⁻¹.

Marinade Preparation

The marinade formulation was adapted from Incili et al. (2020b) with minor modifications for use in this study. The final marinade consisted of 67% water, 15% tomato paste, 7% fresh lemon juice, 3% salt, 2% crushed garlic, 2% pepper paste, 1.5% red pepper flakes, 1% thyme, 0.75% cumin, 0.5% black pepper, and 0.25% sugar.

Preparation of Chicken Wing Meat Samples

Chicken wing meat was purchased in its original retail packaging and kept under chilled conditions during transport to the laboratory. A pathogen inoculum was prepared to a final volume of 500 mL by mixing 10 mL each of *Salmonella* spp. and *L. monocytogenes* cultures with sterile 0.1% peptone water (480 mL). The chicken wings were submerged in the inoculum for 1 min to allow surface contamination, after which excess fluid was drained and bacterial attachment was permitted under aseptic conditions.

The inoculated samples were divided into three experimental treatments: (i) an untreated control (unmarinated), (ii) a marinated control (M), and (iii) marinated samples supplemented with lactic acid bacteria (M-LAB). Control samples were packaged without additional processing. For the M treatment, 250 g of marinade was added per 1 kg chicken wing meat and uniformly distributed. For the M-LAB treatment, the same quantity of marinade was applied and enriched with approximately 10^7 cfu/g of the LAB mixture. In both marinated groups, samples were handled using an identical mixing procedure to ensure homogeneous coating.

pH Analyses

Following microbiological examination, pH determination was carried out using the remaining sample homogenates. The pH values were recorded using a digital pH measurement device (model HI 2211, Hanna Instruments, USA), with the probe placed directly into each homogenized sample.

Microbiological Analysis

On each sampling day, two samples per treatment group were analyzed. Individual chicken wings were transferred into sterile stomacher bags, and 100 mL of sterile 0.1% peptone water was added. Samples were manually agitated for 2 min, after which 1 mL of the rinse solution was collected for serial dilution. Appropriate dilutions were plated on selective or non-selective media, and microbial counts were expressed as cfu.mL⁻¹ of rinse fluid.

Pseudomonas spp. were enumerated on *Pseudomonas* CFC Agar (Merck, Darmstadt, Germany) supplemented with *Pseudomonas* Selective Supplement and incubated at 25 °C for 48 h. Lactic acid bacteria were quantified on MRS Agar (Merck) following incubation at 30 °C for 48 h. Counts of *L. monocytogenes* were obtained using Oxford Listeria Selective Agar (Merck) with incubation at 35 °C for 48 h, while *Salmonella* spp. were determined on XLT4 Agar (Merck) after incubation at 35 °C for 24–48 h. Yeasts and molds were assessed on

DRBC Agar (Merck) incubated at 25 °C for 5 days. Total aerobic mesophilic bacteria (TAMB) were determined on Plate Count Agar (PCA, Merck) after incubation at 30 °C for 48 h. *Enterobacteriaceae* were enumerated on Violet Red Bile Glucose (VRBG) Agar (Merck) following incubation at 37 °C for 24 h.

Statistical Analyses

The study was conducted with three independent replicates. After the microbiological data were converted to log values, the pH data were subjected to statistical analysis. The effects of treatment group, storage temperature, and sampling day, as well as their interactions, were evaluated using analysis of variance (ANOVA). Replicates were included in the model as a random effect to account for variability among repetitions. All statistical analyses were performed using the SPSS 22 (IBM SPSS, USA) package program and the statistical significance level was set at $p < 0.05$.

Results

pH Values

The pH value of the prepared marinade was determined as 3.60. In the control group (unmarinated samples), pH values increased throughout storage at both 4 °C and 8 °C, reaching 6.93 and 6.99, respectively. In the M group, the initial pH value of 4.89 increased to 5.20 by day 14 at 4 °C, whereas it decreased to 4.73 at 8 °C. A similar trend was observed in the M-LAB group, where the pH increased during storage at 4 °C and decreased at 8 °C ($p < 0.05$) (Table 1).

Table 1. pH values in chicken wing samples stored at 4 and 8 °C (n:6)

Application groups	Storage temperature (°C)	Days				
		0	4	8	12	14
Control	4	6.13±0.19 ^{Ax}	6.73±0.08 ^{Ay}	6.89±0.23 ^{Ay}	6.90±0.01 ^{Ay}	6.93±0.05 ^{Ay}
M		4.89±0.17 ^{Bx}	5.74±0.22 ^{Byz}	5.29±0.13 ^{Bxy}	5.42±0.16 ^{By}	5.14±0.18 ^{Bxy}
M-LAB		4.97±0.07 ^{Bx}	5.29±0.08 ^{Cxy}	5.27±0.12 ^{Bxy}	5.30±0.21 ^{BCxy}	5.20±0.21 ^{Bxy}
Control	8	6.13±0.19 ^{Ax}	6.80±0.09 ^{Ay}	6.94±0.23 ^{Ay}	6.94±0.03 ^{Ay}	6.99±0.02 ^{Ay}
M		4.89±0.17 ^{Bx}	5.10±0.13 ^{Cx}	5.10±0.10 ^{Bx}	4.92±0.02 ^{CDx}	4.73±0.03 ^{Cx}
M-LAB		4.97±0.07 ^{Bx}	5.16±0.08 ^{Cx}	5.04±0.05 ^{Bx}	4.86±0.11 ^{Dxy}	4.73±0.15 ^{Cxy}

A-D: Within a column, values assigned different superscript letters indicate statistically significant differences ($p < 0.05$)

x-y: Within rows, values with unlike superscripts differ significantly ($p < 0.05$)

Control: Chicken wing meat with no marinade application

M: Marinated chicken wing

M-LAB represents samples marinated with a LAB-enriched marinade

Salmonella spp. Counts

At the beginning of storage, *Salmonella* populations in the marinated samples were already lower than those of the untreated control. Specifically, the M group exhibited a reduction of approximately 0.6 log₁₀ cfu.mL⁻¹ compared with the Control on day 0 ($p < 0.05$). During refrigerated storage at 4 °C, *Salmonella* counts increased in all treatments; however, the extent of growth differed markedly among groups. By day 14, counts reached 4.9 log₁₀ cfu.mL⁻¹ in the Control, whereas substantially lower levels were detected in the M (4.1 log₁₀ cfu.mL⁻¹) and M-LAB (3.3 log₁₀ cfu.mL⁻¹) groups ($p < 0.05$). A similar trend was observed at 8 °C, where final counts in the Control group were 5.1 log₁₀ cfu.mL⁻¹, while reductions of approximately 0.3 and 0.8 log₁₀ cfu.mL⁻¹ were noted for the M and M-LAB treatments, respectively ($p < 0.05$) (Table 2).

Table 2. *Salmonella* spp. counts in chicken wing samples stored at 4 and 8 °C ($\log_{10}$ cfu.mL⁻¹±SS) (n:6)

Application groups	Storage temperature (°C)	Days				
		0	4	8	12	14
Control	4	5.3±0.1 ^{Ax}	5.6±0.2 ^{Ax}	5.3±0.3 ^{Ax}	5.0±0.1 ^{Axy}	4.9±0.3 ^{Axy}
M		4.7±0.2 ^{Bx}	4.5±0.3 ^{BCxy}	3.7±0.2 ^{BCy}	4.6±0.3 ^{ABxy}	4.1±0.3 ^{Bxy}
M-LAB		4.7±0.1 ^{Bx}	4.3±0.2 ^{Cx}	3.5±0.1 ^{Cy}	3.4±0.2 ^{Cy}	3.3±0.3 ^{Cy}
Control	8	5.3±0.1 ^{Ax}	5.4±0.4 ^{ABx}	5.3±0.1 ^{Ax}	4.8±0.5 ^{Axy}	5.1±0.1 ^{Axy}
M		4.7±0.2 ^{Bx}	4.4±0.3 ^{Cxy}	4.3±0.3 ^{Bxy}	4.1±0.1 ^{BCxy}	3.8±0.4 ^{BCy}
M-LAB		4.7±0.1 ^{Bx}	4.2±0.3 ^{Cxy}	3.4±0.2 ^{Cz}	3.6±0.4 ^{Cyz}	3.3±0.3 ^{Cz}

^{A-C}: Within a column, values assigned different superscript letters indicate statistically significant differences (p<0.05)

^{x-z}: Within rows, values with unlike superscripts differ significantly (p<0.05)

Control: Chicken wing meat with no marinade application

M: Marinated chicken wing

M-LAB represents samples marinated with a LAB-enriched marinade.

L. monocytogenes Counts

Initial *L. monocytogenes* levels in the Control group were 5.3 $\log_{10}$ cfu.mL⁻¹ and increased progressively throughout storage, reaching 6.5 $\log_{10}$ cfu.mL⁻¹ at 4 °C and 7.3 $\log_{10}$ cfu.mL⁻¹ at 8 °C (p<0.05). In contrast, both marinated treatments limited pathogen growth at the end of storage. At 4 °C, *L. monocytogenes* counts in the M and M-LAB groups were reduced by 2.1 and 1.3 $\log_{10}$ cfu.mL⁻¹, respectively, compared with the Control. At 8 °C, the corresponding reductions were 1.0 $\log_{10}$ cfu.mL⁻¹ for the M group and 1.8 $\log_{10}$ cfu.mL⁻¹ for the M-LAB group (p<0.05) (Table 3).

Table 3. *L. monocytogenes* counts in chicken wing samples stored at 4 and 8 °C ($\log_{10}$ cfu.mL⁻¹±SS) (n:6)

Application groups	Storage temperature (°C)	Days				
		0	4	8	12	14
Control	4	5.3±0.1 ^{Ax}	5.6±0.1 ^{BCxy}	6.2±0.1 ^{Cxyz}	6.2±0.2 ^{BCxyz}	6.5±0.5 ^{DEyz}
M		4.6±0.0 ^{Bx}	4.6±0.1 ^{Ax}	4.6±0.1 ^{Ax}	5.1±0.1 ^{Ax}	4.4±0.2 ^{Ax}
M-LAB		4.4±0.1 ^{Bx}	4.4±0.4 ^{Ax}	4.5±0.1 ^{Ax}	5.2±0.2 ^{Ay}	5.2±0.1 ^{ABy}
Control	8	5.3±0.1 ^{Ax}	6.3±0.4 ^{Cy}	7.0±0.3 ^{Dyz}	7.0±0.1 ^{Dyz}	7.3±0.2 ^{Ez}
M		4.6±0.0 ^{Bx}	5.0±0.3 ^{ABxy}	5.8±0.3 ^{BCyz}	6.4±0.3 ^{CDz}	6.3±0.4 ^{CDz}
M-LAB		4.4±0.1 ^{Bx}	4.7±0.3 ^{ABxy}	5.3±0.4 ^{AByz}	5.6±0.4 ^{ABz}	5.5±0.4 ^{BCyz}

^{A-E}: Within a column, values assigned different superscript letters indicate statistically significant differences (p<0.05)

^{x-z}: Within rows, values with unlike superscripts differ significantly (p<0.05)

Control: Chicken wing meat with no marinade application

M: Marinated chicken wing

M-LAB represents samples marinated with a LAB-enriched marinade

Total Aerobic Mesophilic Colony Counts

An overall increase in TAMB was observed in all treatments during storage. At 4 °C, the TAMB level in the M-LAB group exceeded 7.0 $\log_{10}$ cfu.mL⁻¹ by day 4. Under storage at 8 °C, this threshold was surpassed on the same day in both the Control and M-LAB groups, indicating accelerated microbial proliferation at the higher temperature (Table 4).

Table 4. TAMB values in chicken wing samples stored at 4 and 8 °C ($\log_{10}$ cfu.mL⁻¹±SS) (n:6)

Application groups	Storage temperature (°C)	Days				
		0	4	8	12	14
Control	4	6.5±0.3 ^{Ax}	6.3±0.2 ^{ABx}	8.2±0.2 ^{ABy}	9.1±0.2 ^{Dy}	10.3±0.3 ^{Bz}
M		5.9±0.1 ^{Aw}	5.6±0.3 ^{Aw}	7.2±0.4 ^{Ax}	7.6±0.1 ^{Axy}	8.5±0.1 ^{Az}
M-LAB		6.6±0.4 ^{Aw}	7.3±0.3 ^{CDwx}	7.4±0.1 ^{Ax}	8.4±0.4 ^{BCy}	8.6±0.4 ^{Ayz}
Control	8	6.5±0.3 ^{Ax}	7.2±0.2 ^{CDx}	9.6±0.6 ^{Cy}	9.3±0.1 ^{Dy}	10.4±0.2 ^{By}
M		5.9±0.1 ^{Aw}	6.6±0.3 ^{BCw}	7.9±0.6 ^{ABx}	8.6±0.6 ^{CDxy}	9.2±0.2 ^{Ay}
M-LAB		6.6±0.4 ^{Aw}	7.6±0.5 ^{Dx}	8.9±0.1 ^{BCy}	9.2±0.1 ^{Dy}	10.2±0.1 ^{Bz}

A-E: Within a column, values assigned different superscript letters indicate statistically significant differences ($p < 0.05$)

w-z: Within rows, values with unlike superscripts differ significantly ($p < 0.05$)

Control: Chicken wing meat with no marinade application

M: Marinated chicken wing

M-LAB represents samples marinated with a LAB-enriched marinade

Pseudomonas spp. Counts

At day 0, *Pseudomonas* spp. populations in the marinated samples were reduced compared with the control group at 4 and 8 °C, with the difference being significant ($p < 0.05$). Rapid growth was observed in the Control samples, with counts exceeding 7.0 $\log_{10}$ cfu.mL⁻¹ by day 8 at 4 °C and by day 4 at 8 °C. In comparison, *Pseudomonas* growth was delayed in the marinated treatments. On day 8, counts in these groups remained below 6.5 $\log_{10}$ cfu.mL⁻¹ at 4 °C, while values slightly above 7.0 $\log_{10}$ cfu.mL⁻¹ were recorded at 8 °C ($p < 0.05$) (Table 5).

Table 5. *Pseudomonas* spp. counts in chicken wing samples stored at 4 and 8 °C ($\log_{10}$ cfu.mL⁻¹±SS) (n:6)

Application groups	Storage temperature (°C)	Days				
		0	4	8	12	14
Control	4	3.8±0.1 ^{Bw}	5.5±0.1 ^{BCx}	8.1±0.2 ^{Dy}	8.6±0.4 ^{By}	10.7±0.5 ^{Ez}
M		2.7±0.4 ^{Aw}	4.5±0.2 ^{Ax}	6.3±0.4 ^{ABy}	7.1±0.0 ^{Ay}	9.2±0.2 ^{BCDz}
M-LAB		2.5±0.4 ^{Aw}	4.4±0.5 ^{Ax}	6.2±0.3 ^{Ay}	6.8±0.1 ^{Ayz}	7.6±0.1 ^{Az}
Control	8	3.8±0.1 ^{Bx}	7.4±0.3 ^{Dy}	9.3±0.3 ^{Ez}	9.8±0.1 ^{Cz}	9.5±0.4 ^{CDz}
M		2.7±0.4 ^{Aw}	5.4±0.4 ^{BCx}	7.2±0.5 ^{BCDy}	9.9±0.1 ^{Cz}	9.3±0.0 ^{CDz}
M-LAB		2.5±0.4 ^{Av}	5.6±0.3 ^{Cw}	7.5±0.0 ^{CDx}	8.5±0.3 ^{By}	10.1±0.2 ^{DEz}

A-E: Within a column, values assigned different superscript letters indicate statistically significant differences ($p < 0.05$)

w-z: Within rows, values with unlike superscripts differ significantly ($p < 0.05$)

Control: Chicken wing meat with no marinade application

M: Marinated chicken wing

M-LAB represents samples marinated with a LAB-enriched marinade.

Lactic Acid Bacteria Counts

At the start of storage, LAB populations in the control and marinated samples (M) were within a narrow range of 2.5 to 2.6 $\log_{10}$ cfu.mL⁻¹, while the M-LAB treatment exhibited a higher ($p < 0.05$) starting level of approximately 7.0 $\log_{10}$ cfu.mL⁻¹ (Table 6). Throughout storage, LAB counts in the Control and M treatments remained relatively stable, reaching 4.3–4.8 $\log_{10}$ cfu.mL⁻¹ at both temperatures by day 14. In contrast, LAB populations in the M-LAB group increased substantially during storage, attaining values between 8.4 and 9.2 $\log_{10}$ cfu.mL⁻¹ ($p < 0.05$).

Table 6. LAB counts in chicken wing samples stored at 4 and 8 °C ($\log_{10}$ cfu.mL⁻¹±SS) (n:6)

Application groups	Storage temperature (°C)	Days				
		0	4	8	12	14
Control	4	2.6±0.0 ^{Ax}	3.6±0.3 ^{Ay}	3.4±0.4 ^{Axy}	3.6±0.1 ^{Ay}	4.6±0.3 ^{Ay}
M		2.5±0.2 ^{Ax}	3.4±0.3 ^{Ay}	3.5±0.2 ^{Ay}	4.2±0.3 ^{Byz}	4.3±0.4 ^{Az}
M-LAB		7.0±0.1 ^{Bx}	7.5±0.4 ^{By}	7.5±0.2 ^{Cy}	7.7±0.2 ^{Cy}	8.4±0.3 ^{Bz}
Control	8	2.6±0.0 ^{Ax}	3.6±0.3 ^{Ay}	3.5±0.1 ^{Ay}	4.3±0.1 ^{Bz}	4.6±0.3 ^{Az}
M		2.5±0.2 ^{Ax}	3.4±0.2 ^{Ay}	4.5±0.5 ^{Bz}	4.6±0.2 ^{Bz}	4.8±0.2 ^{Az}
M-LAB		7.0±0.1 ^{Bv}	7.4±0.4 ^{Bvw}	8.7±0.6 ^{Dxy}	9.7±0.5 ^{Dz}	9.2±0.1 ^{Cyz}

A-D: Within a column, values assigned different superscript letters indicate statistically significant differences (p<0.05)

v-z: Within rows, values with unlike superscripts differ significantly (p<0.05)

Control: Chicken wing meat with no marinade application

M: Marinated chicken wing

M-LAB represents samples marinated with a LAB-enriched marinade

Enterobacteriaceae Counts

At day 0, no significant differences in *Enterobacteriaceae* counts were detected among treatments (p>0.05) (Table 7). By the end of storage, the highest populations were consistently observed in the Control samples, reaching 8.5 $\log_{10}$ cfu.mL⁻¹ and 8.8 $\log_{10}$ cfu.mL⁻¹ at 4 °C and 8 °C, respectively. In contrast, the lowest *Enterobacteriaceae* counts were recorded in the M-LAB group at both temperatures, with final levels of approximately 6.2 $\log_{10}$ cfu.mL⁻¹ (p<0.05).

Table 7. *Enterobacteriaceae* counts in chicken wing samples stored at 4 and 8 °C ($\log_{10}$ cfu.mL⁻¹±SS) (n:6)

Application groups	Storage temperature (°C)	Days				
		0	4	8	12	14
Control	4	4.7±0.2 ^{Ax}	6.2±0.2 ^{Ay}	6.8±0.2 ^{Ay}	8.5±0.1 ^{Az}	8.5±0.1 ^{Az}
M		5.2±0.3 ^{Ax}	5.4±0.3 ^{Bx}	5.8±0.2 ^{BCxy}	5.7±0.1 ^{Dxy}	6.3±0.2 ^{Cy}
M-LAB		4.9±0.0 ^{Ax}	5.4±0.1 ^{Bxy}	5.6±0.3 ^{Cyz}	6.5±0.1 ^{Cz}	6.2±0.2 ^{Cz}
Control	8	4.7±0.2 ^{Aw}	6.5±0.2 ^{Ax}	6.4±0.5 ^{ABx}	7.7±0.1 ^{By}	8.8±0.1 ^{Az}
M		5.2±0.3 ^{Ax}	5.4±0.1 ^{Bx}	6.4±0.2 ^{ABy}	7.3±0.1 ^{Bz}	7.3±0.1 ^{Bz}
M-LAB		4.9±0.0 ^{Ax}	5.4±0.3 ^{Bx}	5.4±0.1 ^{Cxy}	5.6±0.5 ^{Dxyz}	6.2±0.2 ^{Cyz}

A-D: Within a column, values assigned different superscript letters indicate statistically significant differences (p<0.05)

w-z: Within rows, values with unlike superscripts differ significantly (p<0.05)

Control: Chicken wing meat with no marinade application

M: Marinated chicken wing

M-LAB represents samples marinated with a LAB-enriched marinade

Yeast and Mold Counts

On day 0, the highest yeast and mold count was observed in the Control group (2.5 $\log_{10}$ cfu.mL⁻¹), whereas the lowest was recorded in the M-LAB group (1.4 $\log_{10}$ cfu.mL⁻¹) (p<0.05). Counts increased continuously in all groups throughout storage (p<0.05). At 4 °C, the M-LAB group exhibited the lowest count on day 14 (3.8 $\log_{10}$ cfu.mL⁻¹) (p<0.05). At 8 °C, the highest yeast and mold count at the end of storage was observed in the Control group (5.8 $\log_{10}$ cfu.mL⁻¹), while the lowest was recorded in the M group (4.4 $\log_{10}$ cfu.mL⁻¹) (p<0.05) (Table 8).

Table 8. Yeast and mold counts in chicken wing samples stored at 4 and 8 °C ($\log_{10}$ cfu.mL⁻¹±SS) (n:6)

Application groups	Storage temperature (°C)	Days				
		0	4	8	12	14
Control	4	2.5±0.4 ^{Ax}	3.7±0.2 ^{Ay}	4.4±0.3 ^{Ayz}	4.5±0.4 ^{Dyz}	4.8±0.3 ^{BCyz}
M		1.7±0.3 ^{Bx}	3.5±0.5 ^{Ay}	4.7±0.1 ^{Ay}	5.3±0.3 ^{BCz}	5.8±0.1 ^{Az}
M-LAB		1.4±0.2 ^{Bx}	2.3±0.5 ^{By}	3.3±0.1 ^{Bz}	3.8±0.1 ^{Dz}	3.8±0.3 ^{Dz}
Control	8	2.5±0.4 ^{Aw}	3.5±0.5 ^{ABw}	4.7±0.1 ^{Ax}	5.3±0.3 ^{ABxy}	5.8±0.1 ^{Ayz}
M		1.7±0.3 ^{Bx}	2.4±0.3 ^{Bx}	3.4±0.1 ^{By}	4.6±0.1 ^{CDz}	4.4±0.1 ^{CDz}
M-LAB		1.4±0.2 ^{Bw}	3.3±0.3 ^{ABx}	4.2±0.1 ^{Ay}	5.5±0.2 ^{Az}	5.5±0.4 ^{ABz}

^{A-D}: Within a column, values assigned different superscript letters indicate statistically significant differences (p<0.05)

w-z: Within rows, values with unlike superscripts differ significantly (p<0.05)

Control: Chicken wing meat with no marinade application

M: Marinated chicken wing

M-LAB represents samples marinated with a LAB-enriched marinade

Discussion

The maintenance of the cold chain is critical in poultry processing, as it slows microbial growth, extends shelf life, and reduces public health risks (Arriaga-Lorenzo et al., 2024). However, it has been reported that many refrigerators worldwide operate above the recommended temperature (James et al., 2017), and during the summer months, inadequate temperature control after shopping or during picnics can lead to rapid spoilage of chicken meat, posing a risk to public health. In this study, the effects of LAB mixture (*Lactiplantibacillus plantarum*, *Latilactobacillus sakei*, and *Latilactobacillus curvatus*) added to a marinade on the microbiological quality and shelf life of chicken wings stored at 4 °C and 8 °C were investigated.

The pH value is a key chemical indicator of meat quality (Zaboli et al., 2019). The initial pH of control samples was higher than that of marinated samples (M and M-LAB), likely due to the acidic nature of the marinade (pH 3.60). At 4 °C, pH remained relatively stable in marinated samples, whereas it increased rapidly in controls (Table 1) (p<0.05). This increase may be attributed to proteolytic activity of *Pseudomonas* spp. and the production of ammonia from amino acid metabolism by *Enterobacteriaceae* (Lytou et al., 2019; Ray, 2021). Early increases in *Pseudomonas* spp. counts in controls support this explanation. At 8 °C, a slight decrease in pH was observed in the marinated groups, likely due to enhanced activity of lactic acid bacteria from both the natural microflora and the added LAB, which can produce organic acids and counteract the pH rise induced by proteolytic microorganisms. Previous studies, such as Wang et al. (Wang et al., 2024) reported pH reductions in chicken treated with *L. curvatus* and *L. sakei* at 4 °C. In the present study, pH increased slightly at 4 °C, possibly because the use of marinade imposed additional stress on the LAB, delaying their acidifying effect.

Regarding *Salmonella* spp., comparative analysis revealed no statistically meaningful variation among the experimental treatments during the initial phase of storage (Table 2). However, at 4 °C, differences emerged between M and M-LAB treatments became evident on days 12 and 14 (p < 0.05), indicating that LAB in the marinade exerted an antimicrobial effect over time. At 8 °C, marinated samples exhibited a rapid reduction in *Salmonella*, particularly in the M-LAB group (p<0.05), which is explained by increased metabolic activity of LAB at higher temperatures, leading to the production of antimicrobial compounds. Previous reports describing LAB-based interventions in meat products have documented comparable declines in *Salmonella*, aligning with the outcomes of this study (Hoyle et al., 2009; Serter et al., 2024), although the magnitude of reduction varies depending on sample type, initial contamination, and presence of marinade.

The growth of *L. monocytogenes* was slower in the marinated groups compared to controls at both temperatures (Table 3). At 4 °C, no statistically significant separation was detected between the M and M-LAB treatments (p>0.05). This outcome may be attributed to the initially low pH value (3.60), which could have transiently

constrained the metabolic activity of LAB. At 8 °C, the M-LAB group exhibited the lowest *L. monocytogenes* counts, demonstrating a bacteriostatic effect of the added protective cultures. The ability of *L. monocytogenes* to tolerate acidic conditions (Phan-Thanh et al., 2000), a wide pH range (4.3-9.6) (Olaimat et al., 2018), high salt concentrations, and low temperatures likely explains its survival and growth even under conditions that inactivate *Salmonella*.

Total aerobic mesophilic bacteria (TAMB) exceeded $7 \log_{10}$ cfu.mL⁻¹ earlier in controls than in marinated groups, and the addition of LAB resulted in high TAMB counts (Table 4). Although high TAMB is traditionally associated with spoilage, studies (Hoyle et al., 2009) indicate that high LAB counts do not necessarily correlate with sensory spoilage. In this context, monitoring *Pseudomonas* spp. provides a more relevant indicator of spoilage. *Pseudomonas* spp. counts reached $7 \log_{10}$ cfu.mL⁻¹ on day 8 in controls, day 12 in M, and day 14 in M-LAB at 4 °C, while at 8 °C, the threshold was reached earlier (Table 5), highlighting the protective effect of LAB in delaying spoilage. In a study by Pedonese et al. (2020) the addition of a protective culture significantly reduced the *Pseudomonadaceae* population.

LAB levels recorded in the M-LAB treatment were markedly elevated, indicating that the incorporated protective cultures remained viable throughout storage and underwent active growth, with the most pronounced increases observed at 8 °C (Table 6). *Enterobacteriaceae*, an indicator of hygiene (Zhang et al., 2016), increased more slowly in marinated samples, with the addition of protective cultures enhancing inhibition at 8 °C ($p < 0.05$) (Table 7). Yeast and mold counts were initially lower in marinated samples ($p < 0.05$), and the M-LAB group consistently showed the lowest levels throughout storage, reflecting the antifungal activity of the protective cultures. These findings align with previous studies demonstrating the efficacy of LAB in extending shelf life and reducing spoilage in meat products (Hoyle et al., 2009).

Conclusion

This study highlights the potential of lactic acid bacteria-based bioprotective marinades as a practical strategy to improve the microbiological safety and storage stability of chicken wing meat. The observed suppression of major foodborne pathogens under both refrigerated and temperature-abuse conditions suggests that the application of protective cultures can contribute to enhanced product robustness when cold-chain continuity is compromised. In addition to their effect on pathogenic microorganisms, these cultures moderated the progression of spoilage-related microbiota, resulting in an overall improvement in product quality, particularly at elevated storage temperatures.

Although the influence of the bioprotective marinade on *Enterobacteriaceae* and yeast-mold populations was less pronounced, the combined effects on pathogen control and spoilage delay indicate that LAB-based interventions may function effectively as an additional hurdle within poultry preservation systems. Future research should focus on the selection of LAB strains with improved acid tolerance and broader antimicrobial activity, as well as on optimizing their performance under variable temperature regimes. The integration of such strains into commercial marinades or their development as stable, freeze-dried formulations may facilitate wider industrial and domestic application.

Conflict of interest: No conflict of interest declared.

For Studies with Ethics Committee Approval: "This study is not subject to approval by the Animal Experiments Ethics Committee (HADYEK) in accordance with Article 8 (k) of the Regulation on Working Procedures and Principles of Animal Experiments Ethics Committees. The data, information, and documents presented in this article were obtained within the framework of academic and ethical rules."

Artificial Intelligence Usage Declaration Statement: Artificial intelligence-based tools were used solely for language translation purposes during the preparation of this manuscript. The DeepL Translator was utilized

to translate the text. No artificial intelligence tools were used for data analysis, interpretation, scientific decision-making, or content generation

Data Availability Statement: The data supporting the findings of this study are available from the corresponding author upon reasonable request after publication of the article. Corresponding Author Contact: "enisebegum.gocmez@deu.edu.tr"

CRedit author statement: **EBG:** Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Writing – Original Draft. **Oİİ:** Supervision, Methodology, Validation, Writing – Review & Editing. All authors have read and agreed to the published version of the manuscript.

Acknowledgements: This study was supported by Balıkesir University Scientific Research Projects Unit (BAP) (Project No: 2022/042). One of the authors, Enise Begüm Göçmez, received a YÖK 100/2000 PhD scholarship.

References

- Arriaga-Lorenzo, P., Maldonado-Simán, E., Ramírez-Valverde, R., Martínez-Hernández, P. A., Tirado-González, D. N., & Saavedra-Jiménez, L. A. (2024). Meat cold chain management in Mexican supermarkets. *Theory and Practice of Meat Processing*, 9(2), 100-107. <http://doi.org/10.21323/2414-438X-2024-9-2-100-107>
- Austrich-Comas, A., Serra-Castelló, C., Jofré, A., Gou, P., & Bover-Cid, S. (2022). Control of *Listeria monocytogenes* in chicken dry-fermented sausages with bioprotective starter culture and high-pressure processing. *Frontiers in Microbiology*, 13, 983265. <https://doi.org/10.3389/fmicb.2022.983265>
- Chen, C.-Y., Armstrong, C. M., He, Y., Counihan, K., Atencia, J., Lee, J., Dykes, G., Johnson, K., Koppenhofer, H., Tilman, S., Martinos, S., & Capobianco, J. (2025). Multiplexed Detection of *Salmonella*, *Escherichia coli*, *Campylobacter*, and *Listeria* in Raw Poultry. *Foods*, 14(7), 1137. <https://doi.org/10.3390/foods14071137>
- Erdaw, M. M., & Beyene, W. T. (2022). Trends, prospects and the socio-economic contribution of poultry production in sub-Saharan Africa: a review. *World's Poultry Science Journal*, 78(3), 835-852. <https://doi.org/10.1080/00439339.2022.2092437>
- Fan, Y., Zhang, K., Liu, Q., Chen, Q., Xia, Xiufang., Sun, Fangda., & Baohua, Kong. (2025). Mechanism, application, and prospect of bioprotective cultures in meat and meat products. *Food Chemistry*, 476, 143474. <https://doi.org/10.1016/j.foodchem.2025.143474>
- Hoyle, A. R., Brooks, J. C., Thompson, L. D., Palmore, W., Stephens, T. P., & Brashears, M. M. (2009). Spoilage and safety characteristics of ground beef treated with lactic acid bacteria. *Journal of Food Protection*, 72(11), 2278-2283. <https://doi.org/10.4315/0362-028X-72.11.2278>
- Hulankova, R., Borilova, G., Abdullah, F. A. A., & Buchtova, H. (2018). Microbiological quality of organic chicken meat during refrigerated storage in air and modified atmospheres. *British Poultry Science*, 59(5), 506-513. <https://doi.org/10.1080/00071668.2018.1496399>
- İncili, G. K., Akgöl, M., Aydemir, M. E., Alan, S., Mutlu, M., İlhak, O. I., & Öksüztepe, G. (2020b). Fate of *Listeria monocytogenes* and *Salmonella* Typhimurium in homemade marinade and on marinated chicken drumsticks, wings and breast meat. *Lwt-Food Science and Technology*, 134, 110231. <https://doi.org/10.1016/j.lwt.2020.110231>
- İncili, G. K., İlhak, O. İ., & Çalicioğlu, M. (2025). Inhibitory effect of cell-free supernatants of *Pedococcus acidilactici* and *Latilactobacillus sakei*/*Staphylococcus xylosus* in combination with ethylenediaminetetraacetic acid against *Escherichia coli* O157:H7 strains. *Veterinary Research Forum*, 16(8), 439 - 446 DOI: 10.30466/vrf.2025.2035776.4368

- İncili, G. K., Karatepe, P., & İlhak, O. İ. (2020a). Effect of chitosan and *Pediococcus acidilactici* on *E. coli* O157: H7, *Salmonella* Typhimurium and *Listeria monocytogenes* in meatballs. *LWT*, 117, 108706. <https://doi.org/10.1016/j.lwt.2019.108706>
- James, C., Onarinde, B. A., & James, S. J. (2017). The use and performance of household refrigerators: A review. *Comprehensive Reviews in Food Science and Food Safety*, 16(1), 160-179. <https://doi.org/10.1111/1541-4337.12242>
- Kingkaew, E., Tanasupawat, S. (2023). Application of antimicrobial peptides from lactic acid bacteria in food preservation and human health. In A. Gupta, & R. Prasad (Eds.), *Antimicrobials in Food Science and Technology*. (1st ed., pp. 1–29), CRC Press. <https://doi.org/10.1201/9781003268949>
- Kralik, G., Kralik, Z., Grčević, M., & Hanžek, D. (2018). Quality of chicken meat. *Animal Husbandry and Nutrition*, 63. 10.5772/intechopen.72865
- Lytou, A. E., Tzortzinis, K., Skandamis, P. N., Nychas, G. J. E., & Panagou, E. Z. (2019). Investigating the influence of organic acid marinades, storage temperature and time on the survival/inactivation interface of *Salmonella* on chicken breast fillets. *International Journal of Food Microbiology*, 299, 47-57. <https://doi.org/10.1016/j.ijfoodmicro.2019.03.019>
- Mohammadi, R., Moradi, M., Tajik, H., & Molaei, R. (2022). Potential application of postbiotics metabolites from bioprotective culture to fabricate bacterial nanocellulose based antimicrobial packaging material. *International Journal of Biological Macromolecules*, 220, 528-536. <https://doi.org/10.1016/j.ijbiomac.2022.08.108>
- Ndoye, B., Dicko, M. H., & Gill, C. (2025). Exploring the spoilage microbiota of raw and processed meats under different storage environments and its related profiling methods: a review. *Cogent Food & Agriculture*, 11(1). <https://doi.org/10.1080/23311932.2025.2562177>
- Olaimat, A. N., Al-Holy, M. A., Shahbaz, H. M., Al-Nabulsi, A. A., Abu Ghoush, M. H., Osaili, T. M., ... & Holley, R. A. (2018). Emergence of antibiotic resistance in *Listeria monocytogenes* isolated from food products: a comprehensive review. *Comprehensive Reviews in Food Science and Food Safety*, 17(5), 1277-1292. <https://doi.org/10.1111/1541-4337.12387>
- Ovca, A., Škufca, T., & Jevšnik, M. (2021). Temperatures and storage conditions in domestic refrigerators—Slovenian scenario. *Food Control*, 123, 107715. <https://doi.org/10.1016/j.foodcont.2020.107715>
- Ozturk, B., & Sengun, I. Y. (2025). Effects of cell-free supernatants produced by lactic acid bacteria on the safety and quality of poultry meat. *British Poultry Science*, 1–13. <https://doi.org/10.1080/00071668.2025.2500344>
- Pedonese, F., Torracca, B., Mancini, S., Pisano, S., Turchi, B., Cerri, D., & Nuvoloni, R. (2020). Effect of a *Lactobacillus sakei* and *Staphylococcus xylosus* protective culture on *Listeria monocytogenes* growth and quality traits of Italian fresh sausage (salsiccia) stored at abusive temperature. *Italian Journal of Animal Science*, 19(1), 1363-1374. <https://doi.org/10.1080/1828051X.2020.1844084>
- Phan-Thanh, L., Mahouin, F., & Aligé, S. (2000). Acid responses of *Listeria monocytogenes*. *International Journal of Food Microbiology*, 55(1-3), 121-126. [https://doi.org/10.1016/S0168-1605\(00\)00167-7](https://doi.org/10.1016/S0168-1605(00)00167-7)
- Ray, B. (2021). *Fundamental food microbiology*. CRC Press, 625 p., Boca Raton- Florida
- Serter, B., Önen, A., & Osman, I. I. (2024). Antimicrobial efficacy of postbiotics of lactic acid bacteria and their effects on food safety and shelf life of chicken meat. *Annals of Animal Science*, 24(1), 277-287. <https://doi.org/10.2478/aoas-2023-0081>
- Smaoui, S., Echegaray, N., Kumar, M., Chaari, M., D'Amore, T., Shariati, M. A., ... & Lorenzo, J. M. (2024). Beyond conventional meat preservation: saddling the control of bacteriocin and lactic acid bacteria for clean label and functional meat products. *Applied Biochemistry and Biotechnology*, 196(6), 3604-3635. <http://10.1007/s12010-023-04680-x>

- Wang, Q., Zhang, K., Li, M., Liu, H., Kong, B., & Chen, Q. (2024). Bioprotective potential of *Latilactobacillus sakei* and *Latilactobacillus curvatus* in smoked chicken legs with modified atmosphere packaging. *Food Control*, 164, 110558. <https://doi.org/10.1016/j.foodcont.2024.110558>
- Xu, M. M., Kaur, M., Pillidge, C. J., & Torley, P. J. (2023). Culture-dependent and culture-independent evaluation of the effect of protective cultures on spoilage-related bacteria in vacuum-packaged beef mince. *Food and Bioprocess Technology*, 16(2), 382-394.
- Zaboli, G., Huang, X., Feng, X., & Ahn, D. U. (2019). How can heat stress affect chicken meat quality?—a review. *Poultry science*, 98(3), 1551-1556. <http://dx.doi.org/10.3382/ps/pey399>
- Zdolec, N., Kiš, M., Vukšić, M., Mazija, H., Bazina, I., & Kazazić, S. (2025). Lactic acid bacteria succession, identification and antilisterial capacity in traditionally produced dry-fermented chicken sausage. *Processes*, 13(7), 2216. <https://doi.org/10.3390/pr13072216>
- Zhang, H., Wu, J. & Guo, X. (2016). Effects of antimicrobial and antioxidant activities of spice extracts on raw chicken meat quality. *Food Science and Human Wellness*, 5(1), 39–48, <https://doi.org/10.1016/j.fshw.2015.11.003>.