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Sodium Dodecyl Sulfate and Citric Acid Treatments - Enhance the Shelf-Life and Quality of Super-Chilled Chicken Wings

Siavash Maktabi [*1], Maryam Ghaderi Ghahfarokhi[1], Fatemeh Mohammadi[2]

1- Department of Food Hygiene, Faculty of Veterinary Medicine, Shahid Chamran University of Ahvaz, Ahvaz, Iran. https://orcid.org/0000-0003-3280-7151

2- Graduated from Department of Food Hygiene, Faculty of Veterinary Medicine, Shahid Chamran University of Ahvaz, Ahvaz, Iran. https://orcid.org/0000-0002-5427-220X

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*Corresponding Author E-Mail:
s.maktabi@scu.ac.ir

ABSTRACT

Poultry meat is a valuable source of high-quality protein but remains highly perishable. This study evaluated the effects of sodium dodecyl sulfate (SDS) and citric acid (CA) immersion on microbial stability, chemical quality, and sensory acceptability of chicken wings stored under super-chilling (0–2 °C). Samples (n = 20 per treatment; three independent replicates) were subjected to four treatments: (1) sterile saline (control), (2) 1% SDS, (3) 2% SDS, and (4) 1% SDS + 0.1% CA. After a 15 min immersion, samples were stored for 8 days, and analyses were performed on days 0, 2, 4, 6, and 8. The 2% SDS treatment achieved the greatest microbial reduction, lowering mesophilic and psychrotrophic counts by approximately 1.5–2.0 log CFU/g compared with the control ($p < 0.05$). TVB-N and TBARS values increased progressively in all groups but remained lowest in 2% SDS (TVB-N = 18.6 mg N/100 g on day 8 vs. 31.2 mg N/100 g in control). Sensory scores declined over storage; however, 2% SDS maintained acceptable color and texture up to day 6, while the SDS–CA combination provided superior odor and overall acceptability on day 8. These results indicate that 2% SDS effectively retards microbial and chemical spoilage under super-chilling, with SDS–CA offering additional sensory protection during extended storage.

1-Introduction

Sodium dodecyl sulfate (SDS) is a potent anionic surfactant with well-documented antimicrobial activity, mainly through disruption of bacterial membranes and protein denaturation [1]. Although widely used in cosmetics and hygiene products such as toothpaste and shampoos, SDS has demonstrated toxicological safety at low concentrations [2], encouraging its exploration for food decontamination. Previous research has shown that SDS effectively inhibits Listeria monocytogenes [3] and, when combined with levulinic or lactic acid, can markedly reduce Salmonella spp. and E. coli O157:H7 on food and contact surfaces [4–6]. Its applications have expanded to egg, beef, seafood, and produce decontamination [7–10].

Citric acid (CA), a GRAS compound, enhances antimicrobial activity through acidification and metal ion chelation, disrupting microbial metabolism [11]. When combined with surfactants or oxidizing agents, its inhibitory effects are further amplified [7]. Poultry, particularly popular in regions such as Iran for its affordability and nutritional value [12], remains highly perishable due to its high moisture, near-neutral pH, and nutrient-rich matrix. Common spoilage and pathogenic bacteria (*Pseudomonas*, Enterobacteriaceae, *Brochothrix thermosphacta, Salmonella, Campylobacter*) rapidly deteriorate meat quality [13], underscoring the need for effective preservation strategies.

Combining SDS and CA may offer synergistic protection via membrane disruption, protein denaturation, and acidification [14], particularly when coupled with super-chilling (0 to –2 °C), which slows microbial and enzymatic activity [15]. This study investigates the effects of SDS and SDS–CA immersion treatments on super-chilled chicken wings to (1) evaluate their antimicrobial efficacy, (2) monitor physicochemical changes (pH, TVB-N, TBARS), and (3) assess sensory quality. The findings aim to support the development of practical, cold-chain-compatible decontamination strategies for poultry preservation.

2-Materials and Methods

2.1 Sample Collection and Treatment Protocols

Fresh chicken wings from birds slaughtered on the day of purchase were obtained from local vendors in Ahvaz. A total of 20 chicken wing samples per treatment group were used for each of the three independent experimental replicates (n = 20 × 4 treatments × 3 replicates). Each wing weighed approximately 50–60 g. Samples were rinsed manually under running potable water, drained on stainless-steel mesh screens that had been UV-sterilized, and placed for 5 min in a laminar airflow cabinet to reduce airborne contamination. The wings were then portioned into four treatment groups using sterile polypropylene containers:

Control – immersion for 15 min at ambient temperature in sterile 0.9% (w/v) sodium chloride solution.
SDS 1% – immersion in a 1% (w/v) sodium dodecyl sulfate (SDS) solution.
SDS 2% – immersion in a 2% (w/v) SDS solution.
SDS + Citric Acid – immersion in a mixture of 1% (w/v) SDS with 0.1% (w/v) citric acid.

All solutions were prepared volumetrically in sterilized graduated cylinders. The selection of SDS (1% and 2%) and SDS + citric acid (0.1%) immersion treatments was chosen based on previous studies demonstrating the antimicrobial efficacy of anionic surfactants and organic acids [3, 7, 9-10]. Post-treatment, wings were transferred into UV-sterilized, sealable polyethylene pouches and stored under refrigeration (0–2 °C) for eight days. Analyses

for microbiological, chemical, and sensory quality were conducted on storage days 0, 2, 4, 6, and 8. Each trial was performed independently three times.

2.2 Microbial Enumeration

For microbial testing, 10 g of each sample was minced and homogenized in a stomacher bag with 90 mL sterile saline (0.9% NaCl) for 60 s. Ten-fold serial dilutions were prepared using standard microbiological procedures. Mesophilic aerobic counts were determined on Plate Count Agar (Merck, Germany) incubated at 37 °C for 24 h. Psychrotrophic counts were enumerated on the same medium following incubation at 7 °C for 7–10 days [16]. Coliforms were quantified by plating 1 mL of appropriate dilutions onto Violet Red Bile Agar (VRBA; Merck, Germany) using a double-layer technique, followed by incubation at 37 °C for 24 h. Counts were expressed as colony-forming units per gram (CFU/g) [17].

2.3. Determination of Total Volatile Base Nitrogen (TVB-N)

TVB-N levels were measured via the Conway microdiffusion approach [18]. Briefly, Five grams of homogenized meat were mixed with 60 mL distilled water, 2 g magnesium oxide, and a few drops of silicone-based antifoaming agent. The mixture underwent steam distillation using a Kjeldahl apparatus, with the volatile bases captured in 40 mL boric acid (20 g/L) containing a mixed indicator solution (0.1% methyl red + 0.1% methylene blue in ethanol). The trapped bases were titrated against 0.1 N HCl. TVB-N content (mg/100 g) was computed as:

TVB-N (mg/100 g) = (HCl × N ×14.01 × 100) / sample mass

Where HCl = titrant volume (mL), N = HCl normality.

2.4. Lipid Oxidation Measurement (TBARS)

The extent of lipid oxidation was assessed through thiobarbituric acid reactive substances (TBARS) analysis, following the method of [19]. Five grams of minced sample were blended with 25 mL of 20% trichloroacetic acid and 20 mL distilled water. The homogenate was centrifuged (8,000 × g, 10 min), and 3 mL of the supernatant was combined with 3 mL of 0.02 M thiobarbituric acid in 90% acetic acid. The mixture was heated at 90 °C for 60 min, cooled, and the absorbance was read at 532 nm against distilled water as a blank. Results were expressed as milligrams of malondialdehyde (MDA) per kilogram of sample.

2.5. pH Measurement

Following the approach of [20], 10 g of minced chicken wing were homogenized in 90 mL distilled water, filtered through Whatman No. 1 paper, and the pH was measured using a pre-calibrated digital pH meter (AZ-86555, Taiwan).

2.6. Sensory Assessment

This experiment received prior ethical clearance from the Institutional Review Board and was conducted in line with the Declaration of Helsinki. Ten trained assessors (seven female, three male; aged 24–40 years) participated after providing informed consent. Samples were evaluated for odor, color, texture, and overall acceptability using a 5-point hedonic scale (1 = dislike extremely; 5 = like extremely). Mean scores for each attribute were calculated for every storage day [21].

2.7. Statistical Processing

All tests were performed in triplicate, and results are reported as mean values. Statistical analyses were conducted using Minitab software (Version 18, Minitab Inc., PA, USA). Continuous variables were examined by two-way analysis of variance (ANOVA), using a general linear model (GLM), whereas sensory data (ordinal scale) were analyzed via the Kruskal–Wallis test, followed by Mann–Whitney pairwise comparisons.

3-Results

3.1 Bacteria

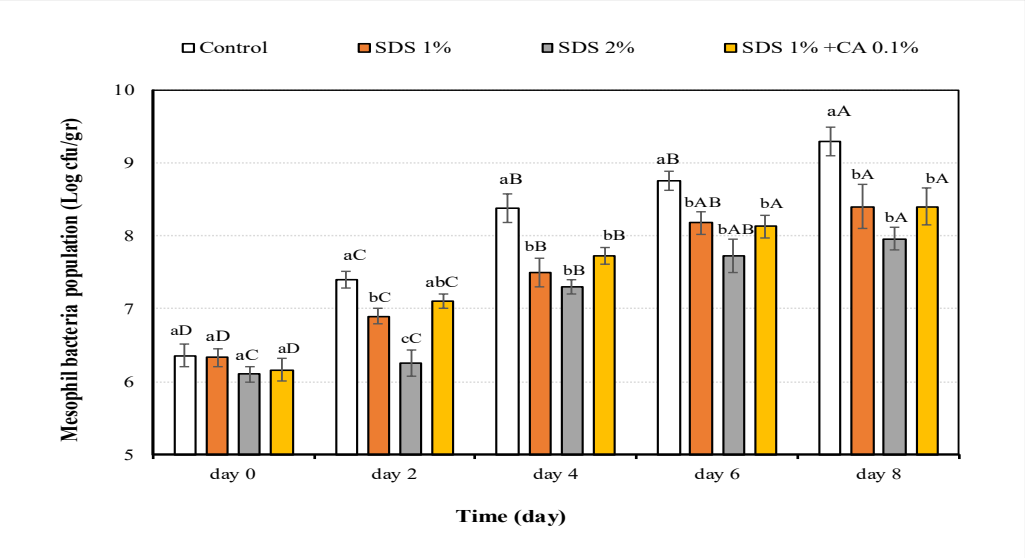
Two-way ANOVA revealed significant main effects of treatment, storage time, and their interaction for mesophilic, psychrophilic, and coliform counts ($p < 0.05$), indicating that microbial behavior during storage differed significantly among treatments (Fig. 1A–C). At Day 0, no statistical differences were detected among treatments ($p > 0.05$), confirming comparable initial contamination levels: mesophiles (6.16–6.36 log CFU/g), psychrophiles (6.00–6.20 log CFU/g), and coliforms (5.60–5.72 log CFU/g).

Across storage, all microbial groups increased progressively ($p < 0.05$), but the magnitude of growth varied substantially among treatments. SDS 2% consistently exhibited the strongest inhibitory effect, demonstrating significantly lower mesophilic counts compared with all other treatments from Day 4 onward ($p < 0.05$). By Day 8, mesophilic populations reached 7.96 ± 0.15 log CFU/g in SDS 2% versus 9.30 ± 0.20 log CFU/g in the control—a 1.34-log reduction. SDS 1% + CA 0.1% and SDS 1% exhibited intermediate values without significant differences between them on several sampling days ($p > 0.05$).

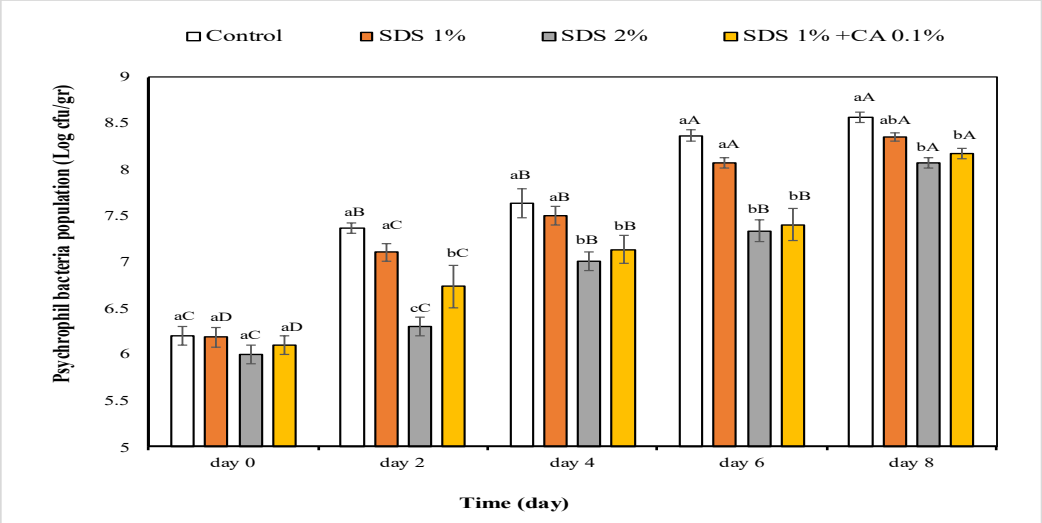
For psychrophiles, treatment differences were evident primarily on Days 2–6 ($p < 0.05$). Although count differences narrowed by Day 8 ($p > 0.05$), SDS 2% consistently maintained the lowest values (≤ 2.15-log increase), indicating delayed spoilage by approximately 48 h relative to the control. Psychrophiles demonstrated the least responsiveness to treatment, showing maximum between-treatment differences of only 0.29 log CFU/g at Day 8.

Coliform populations followed a similar pattern, with significant treatment effects emerging from Day 4 ($p < 0.05$). SDS 2% achieved the greatest suppression, limiting coliform increases to 1.50 log CFU/g by Day 8 compared with 1.67 log CFU/g in the control. The SDS 1% + CA 0.1% treatment provided transient improvement over SDS 1% from Days 4–6 (0.04–0.40 log reduction), but differences were not retained at Day 8 ($p > 0.05$).

Overall, microbiological data clearly identify the efficacy ranking as SDS 2% > SDS 1% + CA 0.1% ≈ SDS 1% > control, with SDS 2% delaying detectable microbial proliferation by more than 48 h across all microbial groups.



(A)



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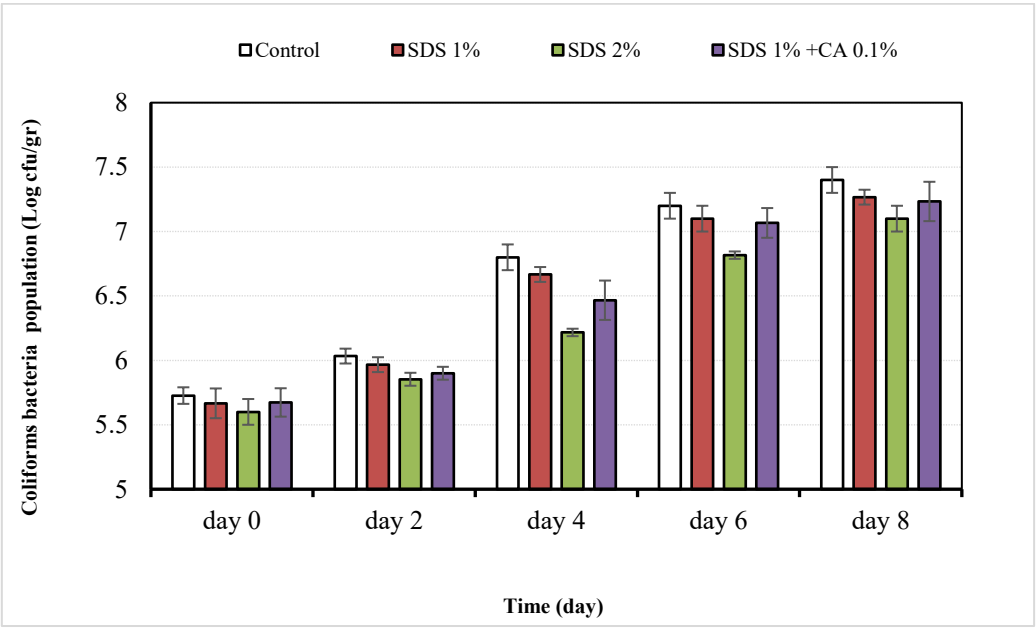


(C)

Figure 1- Population changes of (A) mesophilic populations, (B) psychrophilic population, and (C) coliforms populations in chicken wing samples under super chilled conditions

3.2 Chemical properties

Total Volatile Basic Nitrogen (TVB-N)

TVB-N was significantly affected by treatment, storage duration, and their interaction ($p < 0.05$; Fig. 2A). Baseline values showed no differences among treatments (14.06–16.84 mg/100 g; $p > 0.05$). TVB-N increased steadily throughout storage in all treatments, reflecting progressive proteolysis.

The control group exhibited the most rapid accumulation, reaching **35.00 ± 2.24 mg/100 g** by Day 8, exceeding the commonly accepted spoilage threshold (> 27 mg/100 g). In contrast, SDS 2% maintained the lowest values at every sampling point after Day 4 ($p < 0.05$), attaining **23.61 ± 0.70 mg/100 g** at Day 8—a 32% reduction relative to the control.

Significant group separation appeared by Day 2 for SDS 2% and SDS 1% + CA 0.1% compared with the control ($p < 0.05$). From Days 6–8, all

treated groups differed significantly from the control ($p < 0.05$). SDS 2% also differed from SDS 1% + CA 0.1% on Days 6 and 8 ($p < 0.05$), demonstrating superior inhibition of volatile nitrogen accumulation.

The overall magnitude of TVB-N increase from Day 0 to Day 8 followed the order:

- Control: +18.16 mg/100 g
- SDS 1%: +13.06 mg/100 g
- SDS 1% + CA 0.1%: +11.29 mg/100 g
- SDS 2%: +9.55 mg/100 g

These results verify that SDS 2% most effectively slowed proteolytic deterioration during refrigerated storage.

3.2.1 TBARS

Thiobarbituric Acid Reactive Substances (TBARS)

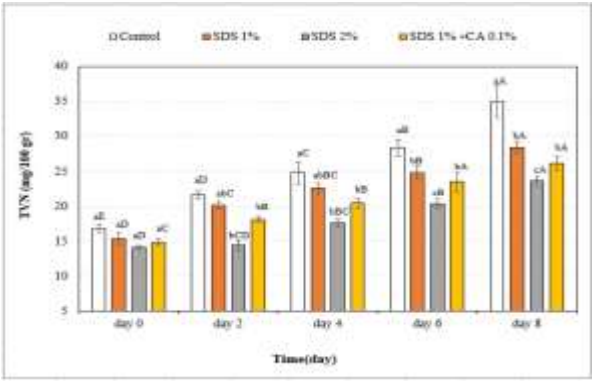
TBARS values increased progressively throughout storage, with significant effects of treatment, storage time, and interaction ($p < 0.05$; Fig. 2B). At Day 0, the SDS 1% group exhibited a slightly higher TBARS value (0.50 ± 0.02 mg MDA/100 g) compared with SDS 2% and SDS 1% + CA 0.1% (both 0.42 mg MDA/100 g; $p < 0.05$).

From Day 2 onward, the control consistently demonstrated the highest TBARS values. By Day 8, lipid oxidation reached 0.82 ± 0.02 mg MDA/100 g in the control, significantly higher than 0.64 ± 0.02 mg MDA/100 g in SDS 2% ($p < 0.01$). SDS 2% also showed significantly lower TBARS than SDS 1% on all sampling days ($p < 0.05$) and lower values than SDS 1% + CA 0.1% on Day 4 ($p < 0.05$).

Changes relative to baseline followed the order:

- Control: +0.34 mg MDA/100 g
- SDS 1%: +0.22 mg MDA/100 g
- SDS 2%: +0.22 mg MDA/100 g
- SDS 1% + CA 0.1%: +0.25 mg MDA/100 g

Although SDS 2% and SDS 1% showed identical net increases, SDS 2% maintained consistently lower absolute values throughout storage, confirming a more stable oxidative profile



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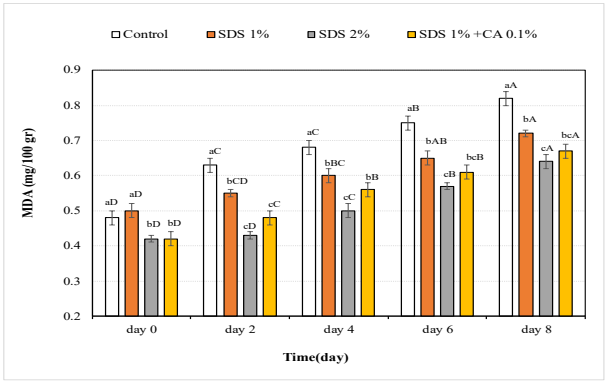

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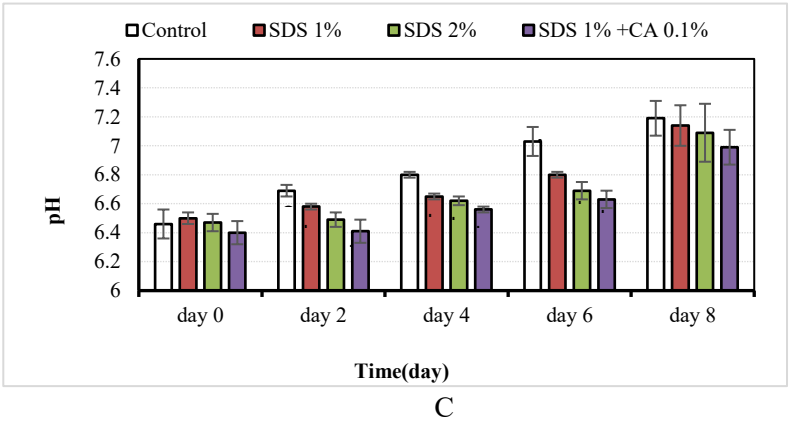

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Figure 2- Changes in mean TVN (A), TBARS (B) and pH (C) values in poultry wing samples under super chilled conditions

3.2.2 pH Dynamics

Treatment, storage day, and their interaction significantly influenced pH ($p < 0.05$). Initial pH values (6.40–6.50) did not differ among groups ($p > 0.05$). All treatments exhibited gradual alkalization over the storage period.

The control group consistently displayed the highest pH values after Day 2. By Day 8, pH reached **7.19 ± 0.12** in the control compared with **6.99 ± 0.12** for SDS 1% + CA 0.1%—a 0.20-unit difference ($p < 0.01$). SDS 1%, SDS 2%, and SDS 1% + CA 0.1% did not differ significantly from each other during Days 0–6 ($p > 0.05$), though all three remained significantly lower than the control from Day 2 ($p < 0.05$).

Total pH increases across storage followed the order:

- Control: +0.73
- SDS 1%: +0.64
- SDS 2%: +0.62
- SDS 1% + CA 0.1%: +0.59

Late-stage increases (Day 6→8) were significant for the control and SDS 1% ($p < 0.05$), while SDS 2% and SDS 1% + CA 0.1% exhibited delayed rises, indicating better resistance to spoilage-associated alkalization.

3.3 Sensory Quality

Sensory evaluation revealed that treatment type, storage time, and their interaction exerted significant effects on all assessed hedonic attributes, including color, odor, texture, and overall acceptance ($p < 0.05$; Table 3). At Day 0, panelists assigned uniformly high scores (5.00 ± 0.00) across all groups, indicating no initial perceptual differences ($p > 0.05$). As storage progressed, a gradual deterioration in sensory quality was observed in all samples; however, treated groups consistently exhibited significantly higher scores compared with the control ($p < 0.01$). The relative performance of treatments followed the order SDS 2% > SDS 1% + CA 0.1% > SDS 1% > control, demonstrating that incorporation of SDS, particularly at 2%, substantially improved sensory stability. In practical terms, SDS 2% extended the sensory shelf life by approximately 2–4 days, depending on the attribute assessed.

Color

The color of treated samples declined at a slower rate compared with the control. SDS 2% maintained significantly higher color scores until Day 6 ($p < 0.05$), suggesting an enhanced ability to preserve visual quality, likely attributable to reduced oxidative discoloration. By Day 8, the SDS 1% + CA 0.1% treatment exhibited the highest color retention (score 3.80), markedly outperforming the control (2.40; $p < 0.01$). No significant differences among the treated groups were detected after Day 4 ($p > 0.05$), indicating a convergence in treatment effects during late storage.

Odor

Odor scores demonstrated a similar protective trend. SDS 2% produced the highest ratings beginning on Day 2 (4.33 vs. 3.80 in control; $p < 0.05$). From Day 4 onward, all treated groups scored significantly higher than the control ($p < 0.01$), reflecting delayed onset of spoilage-associated odors. No significant differences were observed among treated samples after Day 4 ($p > 0.05$), suggesting comparable inhibition of off-odor development among SDS-based treatments.

Texture

Texture degradation followed the expected trajectory of softening over time; however, all treatments mitigated this decline relative to the control. SDS 2% showed the strongest texture preservation, maintaining acceptable firmness through Day 8 (3.60 vs. 2.20 in control; $p < 0.001$). SDS 1% + CA 0.1% stabilized texture primarily during mid-storage (Days 2–6; $p > 0.05$ compared with SDS 2%), yet ultimately declined near the acceptability threshold. The control group fell below the threshold by Day 6, whereas treated samples, especially SDS 2% remained acceptable throughout the evaluation period.

Overall Acceptance

Differences in overall acceptance closely mirrored the individual sensory attributes. All treated samples maintained significantly higher acceptability than the control beginning at Day 2 ($p < 0.01$). No significant differences were detected among treated groups at any time point ($p > 0.05$), indicating that each treatment conferred a meaningful sensory benefit. Importantly, overall rejection occurred by Day 8 in the SDS 2% group, whereas the control group fell below acceptability two days earlier (Day 6). These findings reinforce the role of SDS-based treatments, particularly at 2% concentration, in delaying sensory deterioration and extending practical shelf life.

Table 3 Changes in sensory characteristics of wing samples under super chilled conditions

	Time (days)	Color		Odor		Texture		Overall Acceptance	
Control	0	5.00±0.00	aA	5.00±0.00	aA	5.00±0.00	aA	5.00±0.00	aA
SDS 1%		5.00±0.00	aA	5.00±0.00	aA	5.00±0.00	aA	5.00±0.00	aA
SDS 2%		5.00±0.00	aA	5.00±0.00	aA	5.00±0.00	aA	5.00±0.00	aA
SDS 1% + CA 0.1%		5.00±0.00	aA	5.00±0.00	aA	5.00±0.00	aA	5.00±0.00	aA
Control	2	4.00±0.20	bB	3.80±0.34	aB	3.73±0.30	cB	4.03±0.00	bB
SDS 1%		4.00±0.20	bB	4.06±0.11	aB	3.93±0.30	bcB	4.00±0.00	aB
SDS 2%		4.73±0.23	aAB	4.33±0.11	aB	4.66±0.30	aAB	4.53±0.30	aAB
SDS 1% + CA 0.1%		4.26±0.11	abB	4.00±0.20	aB	4.40±0.20	abA	4.20±0.20	aB
Control	4	3.33±0.30	bB	2.86±0.46	bC	3.00±0.40	bC	3.00±0.00	cB
SDS 1%		3.40±0.34	bB	3.53±0.11	aBC	3.40±0.00	bB	3.40±0.20	bcC
SDS 2%		4.13±0.41	aBC	3.93±0.30	aB	4.13±0.30	aBC	4.06±0.30	aBC
SDS 1% + CA 0.1%		3.66±0.30	abBC	3.46±0.41	aBC	3.60±0.34	abB	3.60±0.40	abC
Control	6	2.60±0.20	bC	1.86±0.23	bD	2.46±0.30	bD	2.33±0.11	bC
SDS 1%		3.40±0.34	aB	3.00±0.40	aCD	3.33±0.11	aB	3.13±0.11	aC
SDS 2%		3.53±0.11	aCD	3.20±0.20	aC	3.73±0.30	aCD	3.53±0.30	aC
SDS 1% + CA 0.1%		3.33±0.30	aCD	3.00±0.40	aC	3.20±0.40	aBC	3.06±0.30	aCD
Control	8	1.53±0.50	bD	1.26±0.23	bD	1.53±0.23	bE	1.13±0.23	bD
SDS 1%		2.60±0.00	aC	2.60±0.52	aD	2.60±0.20	aC	2.60±0.20	aD
SDS 2%		2.30±0.20	aD	2.93±0.11	aC	3.13±0.30	aD	2.93±0.23	aD
SDS 1% + CA 0.1%		2.66±0.30	aD	2.33±0.30	aD	2.73±0.23	aC	2.66±0.11	aD

Results are mean ± standard deviation. Similar letters (a-c) indicate no significant difference between treatments on each measurement day for each sensory attribute at the 95% confidence level. Similar letters (A-D) indicate no significant difference between different days of a treatment for each sensory attribute at the 95% confidence level.

4- Discussion

4.1 Microbiological Shelf-Life Implications

Bacterial populations increased during storage at 0–2 °C in all treatments, yet 2% SDS achieved the strongest inhibition. It delayed the critical mesophilic load (7 log CFU/g) by approximately 48 h compared with the control. Similar delays were observed for psychrotrophs and coliforms, with 2% SDS maintaining counts below threshold until day 6. These findings align with reports demonstrating SDS's concentration-dependent effects on Gram-negative bacteria [4,6,22]. However, unlike studies showing strong SDS–acid synergy [23,24], This discrepancy could stem from differences in product matrix (shrimp versus poultry) or storage temperature. The limited synergism observed between SDS and citric acid in our study agrees with Beuchat et al.[25] but conflicts with Jackson-Davis et al.[26], who reported stronger synergistic effects.

The modest inhibition achieved by 1–2% SDS parallels the observations of del Río et al. [27], who suggested that concentrations ≥ 2.5% may be necessary for more substantial suppression. While 2% SDS was particularly effective against coliforms [28], its reduced performance against psychrophiles supports the temperature-dependent effects noted by Navais et al. [29]. Because bacterial reductions were not achieved and only growth delays were evident, the activity of SDS under these conditions appears bacteriostatic rather than bactericidal. This explains its weaker overall performance compared with SDS–organic acid combinations

reported by Vehapi and Özçimen [30]. Using the 7 log CFU/g criterion, 2% SDS extended refrigerated shelf-life by 48 h for mesophiles and psychrophiles, and by 96 h for coliforms. However, no treatment achieved full microbial suppression, consistent with Saleh et al. [31]. Overall, 2% SDS emerges as a viable bacteriostatic agent for chilled poultry, though higher concentrations or multi-hurdle combinations may be necessary for substantial shelf-life extension.

Future investigations should test higher SDS levels (≥ 2.5%), combinations with ≥ 1% citric acid to counteract matrix effects, incorporation into multi-hurdle preservation systems [32], and efficacy assessments at processing temperatures > 4 °C, where antimicrobial effects may be enhanced [9].

4.2 Chemical Shelf-Life Implications

4.2.1. TVB-N

Total Volatile Base Nitrogen (TVB-N) is widely recognized as a reliable spoilage indicator for poultry, with Iranian Veterinary Standards [33], defining quality categories: < 20 mg/100 g (excellent), 20–24 mg/100 g (acceptable), 25–27 mg/100 g (consume promptly), and > 27 mg/100 g (unacceptable). TVB-N increased in all groups, reflecting progressive proteolysis, consistent with proteolysis reported by [34]). Control samples exceeded the 27 mg N/100 g rejection limit by day 6, while 2% SDS delayed this to day 8 (23.6 mg N/100 g). These findings parallel those of Nikravan et al. [35], who observed reduced TVB-N levels in SC–NEO-treated trout, though our poultry model, showed even greater suppression. Citric acid alone had minimal effect. These results indicate slower protein degradation and align with previous studies [36] showing SDS-mediated suppression of spoilage nitrogen compounds

4.2.2. TBARS

Lipid oxidation remained low (< 1 mg MDA/100 g) across all treatments. The lowest TBARS values occurred in 2% SDS (0.22 mg MDA/100 g) versus the control (0.34 mg MDA/100 g), suggesting reduced oxidative degradation. This limited oxidation, despite poultry's high content of unsaturated fatty acids [37], is likely due to the relatively low fat content of wings. In contrast to Saleh et al. [31], who noted TBARS decreases with organic acid immersion over 6 h, our extended storage period revealed gradual oxidation, explaining the difference. The superior antioxidant performance of SDS over rosemary–citric acid blends reported by Zhang et al. [24] suggests promise for lipid stability in lean poultry cuts.

4.2.3. pH Evolution and Microbial Interactions

pH increased gradually in all treatments (from ~6.4 to ~7.1 by day 8), consistent with volatile base accumulation, driven by volatile base formation from spoilage bacteria [38]. The SDS + CA treatment combination most effectively reduced pH changes (final pH = 6.99), supporting findings by Hajipour et al. and Nkosi et al. [36, 39]. This reduction (0.20 units compared with control) likely reflects inhibition of proteolytic Gram-negative bacteria [40].

4.2.4. Integrated Chemical Shelf-Life Assessment

Overall, SDS 2% was most effective at maintaining poultry quality, delaying TVB-N spoilage thresholds by 2 days, reducing lipid oxidation by 22%, and limiting pH elevation. While citric acid alone was less effective, its combination with SDS improved pH control—though not enough to outperform SDS 2% in overall preservation.

4.3. Sensory Quality Preservation

Sensory deterioration (appearance, texture, odor, overall acceptability) paralleled microbial and chemical changes [41]. Control samples lost odor acceptability by day 4, whereas 2% SDS maintained acceptable sensory scores until day 8. The SDS + CA treatment slightly improved odor retention late in storage but did not exceed SDS 2% overall. These results agree

with prior studies highlighting SDS's ability to preserve tissue structure and surface quality [24,36].

Overall, SDS 2% extended the sensory shelf-life of chicken wings by approximately 2–4 days, offering tangible commercial benefits through reduced spoilage and improved product appearance.

4.3.1. Practical and Mechanistic Implications

The collective results demonstrate that SDS acts through multiple preservation mechanisms: (i) membrane destabilization and leakage of intracellular materials, (ii) inhibition of proteolytic and lipolytic enzyme activity, and (iii) reduced oxygen penetration and surface oxidation. Citric acid contributed mainly by stabilizing pH and enhancing surface cleanliness but showed limited antimicrobial synergy at the tested concentration.

These outcomes highlight SDS's potential as a safe, efficient, and low-cost intervention compatible with industrial chilling operations. However, its bacteriostatic nature implies that SDS should be applied as part of a combined strategy with stronger acid levels, natural antimicrobials, or modified-atmosphere packaging. Future research should explore higher SDS concentrations (≥2.5%), optimized SDS–CA ratios, and validation under commercial-scale conditions to maximize safety and product stability.

5-Conclusion

Overall, 2% SDS demonstrated the most effective control of microbial, chemical, and sensory deterioration in super-chilled chicken wings. The treatment extended product shelf-life by up to four days, primarily through inhibition of microbial growth and slowing of protein and lipid degradation. Although the addition of citric acid produced limited enhancement, it improved pH stability and odor quality toward the end of storage. These findings confirm SDS's promise as a practical antimicrobial and quality-preserving agent in chilled poultry systems and warrant further optimization for industrial application.

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