INTRODUCTION

In recent years, poultry consumption has increased throughout the world (FAO, 2010, 2013); however, poultry has accounted for approximately 11% of foodborne outbreaks (Dewaal et al., 2006). The main pathogens associated with poultry are Salmonella, Clostridium perfringens, Campylobacter, and norovirus (CDC, 2013a). It is well known that Salmonella caused the highest number of outbreaks between 2009 and 2010 in the United States (CDC, 2013b). According to FoodNet2010 data (CDC, 2011), the incidence in the United States of infection from Salmonella and Vibrio has increased 3 and 115%, respectively, for the past 15 yr, whereas the incidence from Campylobacter, Listeria, Escherichia coli O157:H7, Shigella, and Yersinia actually decreased in 2011 compared with 1996–2010 (27, 38, 44, 57, and 52% decrease, respectively).

Among more than 2,500 Salmonella serotypes (FAO/WHO, 2002), the predominant serotypes involved in outbreaks in United States from 2009 to 2010 are Salmonella Enteritidis (76 outbreaks) and Salmonella Typhimurium (27 outbreaks; CDC, 2013b). In general, Salmonella can be isolated from many types of foods including eggs, milk, poultry, and other meats (Dickson and Anderson, 1992; McKee, 2012), especially for Salmonella Typhimurium from eggs (30%), meat (33%, frequently pork), and poultry (10%; FAO/WHO, 2002).
In the poultry industry, contamination with *Salmonella* spp. can occur at various stages of poultry processing such as scalding, defeathering, evisceration, and chilling (Lillard, 1989; Hafez et al., 1997; Ono and Yamamoto, 1999; Buhr et al., 2005; McKeel, 2012). Although chicken is chemically sanitized during processing and subsequently cleaned before packaging, some microorganisms cannot be removed completely, especially for bacteria strongly attached to chicken skin (Ko et al., 2005; Zhang et al., 2011). This is because these microorganisms including *Salmonella* and *Campylobacter* are able to become entrapped in deep skin layers, crevices, or feather follicles, thus becoming protected from chemical agents (Krysinski et al., 1992; Mosteller and Bishop, 1993; Yang et al., 2001; Chantarapanont et al., 2004).

Many antimicrobial agents are approved for poultry processing such as acidified sodium chloride, bromine, chlorine dioxide, cetyl pyridium chloride, organic acids, peracetic acid, trisodium phosphate, sodium metasilicate, monochloramine, electrolyzed water, and hypochlorous acid (chlorine; Bilgili, 2009). Out of these chemicals, chlorine is most commonly used (Izat et al., 1988; James et al., 2006), but with less bactericidal effects (no more than 1 log unit) on chicken carcasses and with gradual reduction of activity due to organic matters (Block, 2000; Russell and Axtell, 2005).

Recently, thiamine dilauryl sulfate (TDS), a kind of vitamin B₁, demonstrated synergistic effects when combined with commercial sanitizers such as chlorine and malic acid in the disinfection of alfalfa seeds, squid, rice, and lettuce (Lee and Ha, 2008; Fransisca et al., 2012; Ha et al., 2012; Park et al., 2012). Ultrasound has also been shown to effectively reduce pathogenic microorganisms when combined with altered pH, temperature, or chemical agents (McClements, 1995; Piyasena et al., 2003; Sagong et al., 2011). However, no research has been conducted to examine the combined effects of sodium hypochlorite (NaOCl) with ultrasound or TDS on bacteria decontamination on chicken skin for 3 attachment types. Therefore, this study was designed to assess antimicrobial efficiency of NaOCl, TDS, and ultrasound on loosely, intermediately, and tightly attached *Salmonella* Typhimurium (inoculated) and mesophilic aerobic bacteria (MAB) and coliforms (noninoculated) on chicken skin.

**MATERIALS AND METHODS**

**Bacterial Strains and Inoculum Preparation**

A poultry isolate of *Salmonella* Typhimurium, having novobiocin (NO; Sigma) and nalidixic acid (NA, Sigma) resistance, was used in this study. The stock culture was stored at −70°C in 0.1 mL of tryptic soy broth (Difco Laboratories, Detroit, MI) containing 50% (vol/vol) glycerol (Fisher Scientific, Itasca, IL). To obtain a working culture, fresh cultures were successively cultured twice at 37°C for 24 h in tryptic soy broth. The cells were allowed to grow to a target concentration of 9 log cfu/mL, which was measured by plating on tryptic soy agar (TSA, Difco Laboratories). The resulting cells were centrifuged at 13,000 × g for 10 min at 4°C and suspended in 10 mL of 0.1% peptone water (PW, Oxoid, Basingstoke, Hampshire, UK). The suspension was diluted with 0.1% PW to yield a final cell concentration of 6 log cfu/mL for inoculation. Bacterial loads were determined by plating on brilliant green agar (Difco Laboratories) containing 25 μg/mL of NO and 25 μg/mL of NA and incubating at 37°C for 24 h.

**Sample Preparation and Inoculation**

Chicken breast skin was obtained from a local market in Anseong, Korea, and stored at 4°C before experiments. The chicken skins were uniformly cut into 10-g pieces using a sterile stainless-steel knife and immediately used. To remove background microorganisms on the chicken skin, samples were treated UV (Sankyo UV Co. Ltd., Seoul, Korea) at 1,000 mW/cm² for 5 min and then washed twice with sterile, distilled water for 2 min. The samples were transferred to sterile Whirl-Pak bags (Whirl-Pak, Nasco, Modesto, CA) and dipped into the prepared *Salmonella* Typhimurium solution for 10 min. The skins were then stored in a biosafety storage room for 1 h at 4°C to allow for the inoculum to attach and immersed in distilled water for 5 min to remove unattached cells. Uninoculated samples were used to assess the treatment effect on MAB and coliforms.

**Disinfection Treatments**

Ultrasound (P 300 H model, 230 V, Hucom System Co., Elmasonic, Kolpingstr, Singen, Germany) was used to physically detach bacteria from the surface of chicken skin. For the treatment, a 28-L ultrasound chamber was filled with 12 L of distilled water and used at an operating frequency of 37 kHz with a power up to 380 W. Sterile glass beakers (250 mL) containing 90 mL of sterile water and inoculated samples were placed inside of the 28-L ultrasound chamber with 12 L of distilled water. Then inoculated samples were exposed to the ultrasound for 5 min.

For chemical treatments, NaOCl (12%, Shimadzu Co., Kyoto, Japan) at 100 or 200 mg/kg and TDS at 1,000 mg/kg were prepared in sterile deionized water, whereas the sterile deionized water was used for a control. All chemical solutions, were freshly prepared immediately before use. Experiments were repeated 3 times.

**Enumeration of Microorganisms**

Microbiological analysis was conducted as described in Zhang et al. (2013) with some modifications. Skin samples (10 g) treated with physical or chemical disinfections, or both, were aseptically placed to 90 mL of 0.1% PW in a sterile glass beaker. The samples were
shaken at 200 rpm for 5 min in a shaking incubator (VS-101Si, Vision Science, Daejeon, Korea), and recovered cells were classed as loosely attached cells. The rinsed skins were then transferred to a new Whirl-Pak bag having the same amount of PW, stomached for 1 min (Stomacher, SH-IIM, Elmex, Tokyo, Japan), and assessed for intermediately attached cells. Finally, the rinsed and stomached skins were transferred to a sterile bottle and physically ground with the same amount of PW using a blender (SMX-760J, Shinil, Seoul, Korea) to assess for tightly attached cells. With the serial 10-fold dilutions of rinsed, stomached, or ground samples, 3 types of bacteria (MAB, coliform, and Salmonella Typhimurium) were assessed in duplicate on plate count agar (Difco Laboratories), and brilliant green agar containing 25 μg/mL of NO and 25 μg/mL of NA, respectively.

### Color and Texture Measurement

Skin color was assessed at 5 locations on each sample for lightness (L*), redness (a*), and yellowness (b*) using a Color Difference Meter (UltraScan PRO, HunterLab Co., Reston, VA). Skin texture was determined by stretching the skin for shear force values using a Texture Analyzer (TAHDi/500, TAHD Co., SMS, UK) at a test speed of 1.00 mm/s and trigger force of 0.4903 N, as described by Salim et al. (2012). All experiments were performed 3 times on a 3 different days.

### Field Emission Scanning Electron Microscopy

Field emission scanning electron microscopy (FE-SEM: Sigma, Carl Zeiss, Germany) was conducted to observe population changes of Salmonella Typhimurium on chicken skin after treatment with 200 mg/kg NaOCl or ultrasound alone, and combined 200 mg/kg NaOCl/ultrasound for 5 min in comparison with water controls. Chicken skins inoculated with Salmonella Typhimurium (8 log cfu/mL) were gently washed with sterile water, fixed overnight with 2% glutaraldehyde (Sigma, St. Louis, MO) in PBS (pH 7.2, Sigma, St. Louis, MO) at 4°C (primary fixation), and postfixed in 2% osmium tetroxide (OsO4, Sigma, St. Louis, MO) for 1 h. Samples were then washed in PBS for 15 min to remove the fixation solution and then dehydrated by exchanging the graded ethanol series (50, 60, 70, 80, 90, and 100%). All steps in the gradient ethanol change involved 15 min exposure with duplication. Samples were dried in a freeze dryer for 3 d, coated with gold palladium, and observed in FESEM. The FESEM was operated at an accelerated voltage of 5 kV in 5 mm working distance. The digitized images of Salmonella Typhimurium were collected for further analysis.

### Statistical Analysis

All bacterial numbers were transformed to log cfu per gram for statistical analysis. The data were analyzed by the ANOVA procedure using SAS software (version 9.1, SAS Institute Inc., Cary, NC) for a completely randomized design. Differences between means were studied with Duncan’s multiple-range test, and significant differences were reported at P < 0.05.

### RESULTS AND DISCUSSION

The mean populations of inoculated Salmonella Typhimurium and native MAB and coliforms were evaluated for loosely, intermediately, and tightly attachments on chicken skin before and after chemical (NaOCl, TDS)/physical (ultrasound) treatments.

In our study, the populations of intermediately and tightly attached MAB in chicken skin was 6.69 and 6.56 log cfu/g, respectively, with no significant difference (P > 0.05, Table 1). However, the loosely MAB count was 5.84 log cfu/g, which is significantly different from the previous 2 attachment types. Also, loosely (4.61 log cfu/g), intermediately (5.06 log cfu/g), and tightly (5.29 log cfu/g) attached coliforms existed in chicken skin, respectively. Naturally existing MAB and coliforms had more tightly attached cells than intermediately and loosely attached cells. It can be hypothesized that bacteria are able to penetrate underneath and proliferate as firmly attached to skin due to the damaged skin formed during commercial processing, especially the defeathering process including entails scalding and picking (Notermans and Kampelmacher, 1975; Lilard, 1988).

The efficacy of each treatment against loosely, intermediately, and tightly attached MAB, coliforms, and Salmonella Typhimurium are shown in Tables 2 to 4. No single application of NaOCl (100–200 mg/kg), TDS (1,000 mg/kg), and ultrasound (37 kHz, 380 W) reduced MAB and coliforms more than 0.15 log cfu/g, regardless of attachment type, except the loosely attached cells (0.35–0.41 cfu/g) at 200 mg/kg NaOCl (Table 2). These results are consistent with the previous research findings indicate that the NaOCl treat-

| Table 1. Populations (log cfu/g) of loosely, intermediately, and tightly attached mesophilic aerobic bacteria (MAB) and coliforms in chicken skin |
|------------------|------------------|------------------|
| Item             | Loosely          | Intermediately   | Tightly          |
| MAB              | 5.84 ± 0.18      | 6.69 ± 0.09      | 6.56 ± 0.14      |
| Coliforms        | 4.61 ± 0.05      | 5.06 ± 0.04      | 5.29 ± 0.04      |

*Means within a row with no common superscripts are different (P < 0.05).
ment at 50 to 400 mg/kg significantly reduced loosely attached cells on chicken breast skins compared with firmly attached cells (Tamblyn et al., 1997). Although NaOCl is commonly used in poultry chiller, it is believed that the chemical does not easily access the bacteria in ridges and crevices on poultry skin (Lillard, 1989). In addition, chlorine (NaOCl) at 50 mg/kg causes carcass discoloration, off-flavor, and residual chlorine with tri-halo methane, a potential carcinogenic byproduct (Chang et al., 2000; Kim et al., 2008; Buncic and Sofos, 2011; McKee, 2012). With a single antimicrobial agent, both tightly and intermediately attached cells are not effectively removed over the loosely attached cells. As a result, many studies have focused on hurdle technology with multiple applications for efficient and rapid decontamination on poultry and other food processing (McKee, 2012; Ahn et al., 2013; Oladunjoye et al., 2013).

In this study, maximum decontamination (0.34–0.58 cfu/g) of MAB populations were achieved by treatment with 200 mg/kg NaOCl and 1,000 mg/kg TDS, except the tightly attached cells (0.04 cfu/g), followed by 100 mg/kg NaOCl/1,000 mg/kg TDS, and 200 mg/kg NaOCl alone, which were not significantly different from each other (P > 0.05; Table 2). A high decontamination (0.31 cfu/g) of loosely attached coliforms was also observed when combined 200 mg/kg NaOCl and ultrasound although not statistically different from the 200 NaOCl alone (Table 3). Ha et al. (2012) reported that NaOCl, when combined with 2,000 mg/kg TDS, reduced MAB by 4.90 log cfu/g in head lettuce whereas NaOCl and TDS alone reduced MAB by 2.63 and 0.88 log cfu/g, respectively. Park et al. (2012) reported that the combination of 300 mg/kg NaOCl and 1,000 mg/kg TDS were more effective in eliminating Aeromonas hydrophila in squid than any single application. Lee and Ha (2008) demonstrated that the use of TDS with NaOCl led to synergistic antimicrobial effects against total mesophilic bacteria and coliforms in rice. However, our study showed that NaOCl/TDS combination did not effectively reduce the number of bacteria on chicken skin, except the loosely attached cells, presumably due to the difference in food item and surface property.

The combination of 200 mg/kg NaOCl and ultrasound (37 kHz, 380 W) resulted in the best population reduction (P < 0.05) for MAB (0.38–0.75 log cfu/g) and coliforms (0.35–0.43 log cfu/g) regardless of attachment type (Tables 2 and 3). Unlike the mixture of 2 chemicals, which only affected loosely attached cells, the co-treatment of physical (ultrasound) and chemical (200 mg/kg NaOCl) agents effectively reduced populations of all bacteria attached to poultry skin differently. This suggests that the physical treatment of ultrasound may be needed to ensure that NaOCl is properly distributed

<table>
<thead>
<tr>
<th>Treatment</th>
<th>TDS/US</th>
<th>Loosely</th>
<th>Intermediately</th>
<th>Tightly</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOCl (mg/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>−</td>
<td>0.13 ± 0.06&lt;sup&gt;a&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
<td>0.05 ± 0.13&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
<td>0.02 ± 0.12&lt;sup&gt;a&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
</tr>
<tr>
<td>200</td>
<td>TDS</td>
<td>0.35 ± 0.07&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
<td>0.24 ± 0.02&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
<td>0.03 ± 0.27&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
</tr>
<tr>
<td>0</td>
<td>US</td>
<td>0.1 ± 0.01&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
<td>−0.14 ± 0.09&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;y&lt;/sub&gt;</td>
<td>−0.06 ± 0.09&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;y&lt;/sub&gt;</td>
</tr>
<tr>
<td>200</td>
<td></td>
<td>0.37 ± 0.16&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
<td>0.16 ± 0.17&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
<td>0.06 ± 0.14&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td>0.58 ± 0.13&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
<td>0.34 ± 0.09&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;y&lt;/sub&gt;</td>
<td>0.04 ± 0.20&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;y&lt;/sub&gt;</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>0.07 ± 0.22&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
<td>0.03 ± 0.08&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
<td>−0.01 ± 0.05&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
</tr>
<tr>
<td>200</td>
<td></td>
<td>0.43 ± 0.06&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
<td>0.18 ± 0.10&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
<td>0.35 ± 0.05&lt;sup&gt;b&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
</tr>
<tr>
<td>100</td>
<td>US</td>
<td>0.75 ± 0.12&lt;sup&gt;a&lt;/sup&gt;&lt;sub&gt;x&lt;/sub&gt;</td>
<td>0.38 ± 0.10&lt;sup&gt;a&lt;/sup&gt;&lt;sub&gt;y&lt;/sub&gt;</td>
<td>0.47 ± 0.14&lt;sup&gt;a&lt;/sup&gt;&lt;sub&gt;y&lt;/sub&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Means within a column with no common superscripts are different (P < 0.05).

<sup>x</sup>Means within a row with no common superscripts are different (P < 0.05).

<sup>1</sup>TDS: thiamine dilauryl sulfate (1,000 mg/kg). US: ultrasound treatment (frequencies of 37 kHz, power of 380 W, time of 5 min).
Table 4. Reduction efficacy (log cfu/g) of NaOCl alone, NaOCl/TDS, and NaOCl/US against loosely, intermediately, and tightly attached Salmonella Typhimurium in chicken skin.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>TDS/US</th>
<th>Loosely</th>
<th>Intermediately</th>
<th>Tightly</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaOCl (mg/kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>—</td>
<td>0.37 ± 0.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.47 ± 0.03&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.1 ± 0.12&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>200</td>
<td>TDS</td>
<td>0.41 ± 0.20&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.51 ± 0.02&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.24 ± 0.09&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>100</td>
<td>US</td>
<td>0.13 ± 0.08&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.19 ± 0.06&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.01 ± 0.13&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>200</td>
<td>US</td>
<td>0.14 ± 0.11&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.27 ± 0.13&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.01 ± 0.15&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>0</td>
<td>US</td>
<td>0.22 ± 0.20&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.08 ± 0.16&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.15 ± 0.18&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>100</td>
<td>US</td>
<td>0.51 ± 0.24&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.34 ± 0.11&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.31 ± 0.11&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>200</td>
<td>US</td>
<td>0.83 ± 0.30&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.99 ± 0.13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.54 ± 0.19&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Means within a column with no common superscripts are different (P < 0.05).
<sup>b</sup>Means within a row with no common superscripts are different (P < 0.05).
<sup>c</sup>TDS: thiamine dilauryl sulfate (1,000 mg/kg). US: ultrasound treatment (frequencies of 37 kHz, power of 380 W, time of 5 min).

Using FESEM micrographs, the status of Salmonella Typhimurium attachments on flat and ridges/crevices areas of skin were visualized (Figures 1 and 2). The high populations of loosely attached Salmonella Typhimurium on the water (control) skin (Figure 1a) were gradually reduced after the treatments of ultrasound (Figure 1b), NaOCl (Figure 1c), and NaOCl/ultrasound (Figure 1d). These visual images also demonstrated that the NaOCl/ultrasound combination resulted in the best bactericidal effect.

Salmonella on poultry skin is mostly located in the feather follicles and crevices in addition to flat surface (Thomas and McMeekin, 1980; Kim et al., 1996; Jang et al., 2007). In this study, a large number of Salmonella was entrapped in the ridges and crevices after a water treatment (Figure 2a), which was minimally eliminated after ultrasound and NaOCl alone (Figure 2b and 2c) but remarkably eliminated by NaOCl/ultrasound (Figure 2d). These results agree with the previous reports that pathogens in crevices or fold areas are difficult to remove with single treatments (Thomas and McMeekin, 1980; Noriega et al., 2011). Yang et al. (2001) reported that Salmonella and Campylobacter on chicken skin cannot be removed effectively by chlorine due to the interference of oil between the sanitizers and the surface. Therefore, the development of new technologies to deliver disinfectants into the colonization sites on chicken skin is required. Ultrasound could physically detach microorganisms from the skin surface and thus enhance the action of NaOCl on the pathogens (Povey and Mason, 1998; Piyasena et al., 2003; Demirdoven and Baysal, 2009).

In poultry meat, color and visual appearance are important attributes to consumers (Karaoglu et al., 2004; Sharma et al., 2013). From a food safety standpoint, chicken skin acts as a protective shield against mechanical damage during processing (Lucas and Stettenheim, 1972). Weak skin is more susceptible to mechanical tears, leading to a low quality meat and reducing shelf life (Fletcher and Thomason, 1980; Salim et al., 2012). In this study, the color and texture properties of chicken skin were evaluated following the treatments of water (control), NaOCl, TDS, ultrasound, and NaOCl/...
ultrasound or NaOCl/TDS for 5 min. Both color values (L*, a*, and b*) and tearing shear force were not significantly affected by any treatments ($P > 0.05$), indicating that no treatment would significantly change chicken skin quality (Table 5).

In conclusion, the present study demonstrates that microorganisms that are tightly and intermediately attached to skin were more resistant to chemical disinfectants than loosely attached cells. As it relates to physical and chemicals treatments, the combination of physical (ultrasound) and chemical (NaOCl) treatment resulted in more effective decontamination than single or chemical/chemical combination (NaOCl/TDS), with no quality loss on skin color and texture. However, antimicrobial activity depends on the microbial strain (Piyasena et al., 2003). Some strains may be resistant to combined physical and chemical treatments. For this reason, other foodborne pathogens isolated from poultry should be conducted before applying these treatments in food processing plants. And additional

![Image](https://example.com/image.png)

**Table 5.** Color parameters (L*, a*, and b*) and shear force values (kg/cm$^2$) for chicken skin treated with NaOCl alone, NaOCl/TDS, or NaOCl/US.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>TDS/US</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>Shear force (kg/cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>—</td>
<td>84.25 ± 1.50&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>3.94 ± 0.47&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>13.26 ± 0.54&lt;sup&gt;NS&lt;/sup&gt;</td>
<td>0.28 ± 0.04&lt;sup&gt;NS&lt;/sup&gt;</td>
</tr>
<tr>
<td>100</td>
<td>—</td>
<td>84.03 ± 1.88</td>
<td>2.75 ± 0.98</td>
<td>13.23 ± 1.15</td>
<td>0.25 ± 0.02</td>
</tr>
<tr>
<td>200</td>
<td>—</td>
<td>83.79 ± 0.90</td>
<td>3.67 ± 1.08</td>
<td>12.83 ± 1.26</td>
<td>0.28 ± 0.05</td>
</tr>
<tr>
<td>0</td>
<td>TDS</td>
<td>84.43 ± 0.38</td>
<td>2.98 ± 0.74</td>
<td>13.47 ± 0.71</td>
<td>0.27 ± 0.02</td>
</tr>
<tr>
<td>100</td>
<td>TDS</td>
<td>84.65 ± 1.09</td>
<td>3.95 ± 1.00</td>
<td>12.26 ± 0.68</td>
<td>0.29 ± 0.03</td>
</tr>
<tr>
<td>200</td>
<td>TDS</td>
<td>84.58 ± 1.11</td>
<td>3.87 ± 0.62</td>
<td>13.80 ± 0.59</td>
<td>0.28 ± 0.06</td>
</tr>
<tr>
<td>0</td>
<td>US</td>
<td>84.57 ± 0.41</td>
<td>3.48 ± 0.07</td>
<td>12.15 ± 0.22</td>
<td>0.32 ± 0.08</td>
</tr>
<tr>
<td>100</td>
<td>US</td>
<td>84.15 ± 1.59</td>
<td>3.39 ± 0.19</td>
<td>13.91 ± 1.45</td>
<td>0.24 ± 0.03</td>
</tr>
<tr>
<td>200</td>
<td>US</td>
<td>84.35 ± 0.22</td>
<td>3.01 ± 1.16</td>
<td>13.52 ± 0.97</td>
<td>0.26 ± 0.03</td>
</tr>
</tbody>
</table>

<sup>NS</sup>Means within a column with common superscripts are not different ($P > 0.05$).

<sup>1</sup>L* (lightness), a* (redness), b* (yellowness).

<sup>2</sup>The means and SD were calculated based on 15 replicates (color) and 5 replicates (texture), respectively.

<sup>3</sup>TDS: thiamine dilauryl sulfate (1,000 mg/kg). US: ultrasound treatment (frequencies of 37 kHz, power of 380 W, time of 5 min).
research on the efficacy of NaOCl/ultrasound is needed to verify whether these findings are practically applicable to the poultry industry.

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REFERENCES


Figure 2. Electron micrographs of Salmonella Typhimurium entrapped in ridges and crevices of chicken skin treated with disinfectants at room temperature. (a) Salmonella Typhimurium in water control; (b) Salmonella Typhimurium treated with ultrasound; (c) Salmonella Typhimurium treated with 200 mg/kg NaOCl; (d) Salmonella Typhimurium treated with combined NaOCl/ultrasound. Images were taken at magnification of 5.00 K × (bar = 3 μm). Color version available in the online PDF.
TREATMENT ON BACTERIA ATTACHED TO CHICKEN SKIN


