The antimicrobial effect of thiamine dilauryl sulfate in tofu inoculated with *Escherichia coli* O157:H7, *Salmonella* Typhimurium, *Listeria monocytogenes* and *Bacillus cereus*

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Abstract Thiamine dilauryl sulfate (TDS) is a food additive that is used as a bactericidal agent. This study examines the antimicrobial effect of TDS on tofu inoculated with *Escherichia coli* O157:H7, *Salmonella* Typhimurium, *Listeria monocytogenes*, and *Bacillus cereus*. Tofu was inoculated with 100 µL of each microorganism and TDS solution (0.1, 0.5, 1, and 2%) was added to all bags, which were stored at 5 and 25 °C for 5 days. Sensory evaluations were conducted with tofu stored at 5 °C. At 5 °C, with a 2% TDS, *E. coli* O157:H7, *S. Typhimurium*, *L. monocytogenes*, and *B. cereus* were reduced by 0.29, 0.36, 0.70, and 1.47 log CFU/g, respectively. None of the sensory characteristics of tofu treated with TDS were significantly different from those of the control. Consequently, this study shows the potential of TDS as an antimicrobial agent with a practical application in tofu to ensure food safety.

Keywords Antimicrobial effects · Foodborne pathogens · Food safety · Thiamine dilauryl sulfate · Tofu

Introduction

Tofu (soybean curd) is a well-known, traditional soy-based food that contains high-quality protein. It is considered healthy because it is low in calories and rich in protein, iron, magnesium, and calcium [1]. Today, the consumption of tofu has increased globally due to its widespread acceptance and health benefits [2]. However, tofu can be easily spoiled by microorganisms due to its high protein and water content and neutral pH [3]. Despite being stored and distributed under refrigerated conditions, tofu has a short shelf life. Therefore, antimicrobial intervention is necessary to improve the safety and quality of tofu.

Spoiled tofu has a sour taste and unpleasant odor caused by bacterial growth. The spoilage of tofu is mainly caused by *Acinetobacter calcoaceticus*, *Bacillus cereus*, *Klebsiella pneumoniae*, and *Xenorhabdus luminescens* [4]. Some foodborne pathogens such as *B. cereus*, *Staphylococcus aureus*, and *Enterobacteriaceae* have been found in commercial tofu [3, 5]. In addition, several outbreaks of foodborne illness by pathogenic bacteria have been found to be from tofu. In Seattle and Washington state, an outbreak of yersiniosis was reported [6, 7]. An outbreak of shigellosis occurred in commercial tofu [8]. In addition, unpackaged tofu sold in Thailand was contaminated with *Escherichia coli*, *Salmonella* spp., and *Enterococcus* spp., which are more predominant in unpackaged than packaged tofu [2].

E. coli O157:H7 is an enterohemorrhagic, Gram-negative, facultative anaerobic bacterium that produces verotoxin. The route of infection is mainly through meat, dairy products, fruit, and water [9]. *E. coli* O157:H7 causes various diseases such as diarrhea, hemorrhagic colitis, and hemolytic-uremic syndrome [10]. *Salmonella* Typhimurium is Gram-negative, facultative bacterium that is found

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in humans and warm-blooded animal hosts. It is sometimes transferred to food by contamination, often via stool [11]. It causes a foodborne disease called salmonellosis that is widespread globally [12]. *L. monocytogenes* is a Gram-positive bacterium that is widespread in the environment [13]. It can grow under refrigerated conditions and causes the foodborne illness listeriosis [14]. The reported frequency of listeriosis is low, but the mortality rate is higher than that of other bacteria causing foodborne illnesses [15]. *B. cereus* is known as a facultative anaerobic, spore-forming bacterium that is widespread in nature [16]. It causes a foodborne illness and produces diarrheal and emetic toxins [17].

Thiamine dilauryl sulfate (TDS), a vitamin B1 derivative, is a food additive that is used as a food preservative and an antimicrobial agent. It is also used as a nutrient fortifying agent containing nutritional value of vitamin B1. In Korea, TDS has been approved as a food additive with a non-toxic nature and it is widely used in the preservation of noodles. According to Kim et al. [18], TDS has a greater antimicrobial effect on Gram-positive bacteria than on Gram-negative bacteria. They noted that TDS can pass through the protoplasm of bacteria and interrupt enzyme activity. TDS also has advantages that can improve membrane transport ability and maintain its antimicrobial properties by involvement in a variety of metabolic processes such as carbohydrate metabolism [19].

Many researchers have reported the antimicrobial effect of TDS in various food. In a previous study, Choi et al. [20] reported the antimicrobial effect of TDS against *E. coli* O157:H7, *S. Typhimurium*, *L. monocytogenes*, and *B. cereus* spores in custard cream. The preservative activity of TDS has also been evaluated in sterilized milk and apple juice [19]. Fransisca and Feng [21] reported the inactivation of *E. coli* O157:H7 in alfalfa, broccoli, and radish seeds using TDS. Many other researchers have reported synergistic effect of TDS with other chemicals such as malic acid, hydrogen peroxide, and chlorine in various foods [22–24].

However, the inactivation of foodborne pathogens in tofu with TDS treatment has not been reported yet. Therefore, this study investigates the antimicrobial effect of TDS for the reduction of *E. coli* O157:H7, *S. Typhimurium*, *L. monocytogenes*, and *B. cereus* in commercial tofu.

Materials and methods

Bacterial strains

Three strains of *E. coli* O157:H7 (ATCC 35150, ATCC 43894, ATCC 43895), *S. Typhimurium* (ATCC 19585,

ATCC 14028, ATCC 6994), *L. monocytogenes* (ATCC 7644, ATCC 19111, ATCC 19115), and *B. cereus* (T1, T2, T3), which were isolated from spoiled tofu, were combined to make a cocktail for this study. A stock culture was stored at -80°C and each strain was cultured in 10 mL of tryptic soya broth (TSB; Oxoid, Basingstoke, Hampshire, UK) at 37°C for 24 h.

Sample preparation and inoculation

Tofu purchased from a local supermarket (Seoul, Korea) was dispensed into a sterilized bag (Whirl-pak, 19×30 cm; Nasco, Fort Atkinson, WI, USA). Eight grams of solid tofu and 2 mL of tofu filling water, which was packed with the tofu to ensure safe distribution in the plastic container, were used together. The tofu samples were inoculated with 100 μL of each culture cocktail. Final inoculum levels of *E. coli* O157:H7, *S. Typhimurium*, *L. monocytogenes*, and *B. cereus* were 6.05 ± 0.10 , 6.20 ± 0.15 , 6.63 ± 0.14 and 4.24 ± 0.34 log CFU/mL, respectively.

Determination of TDS concentrations

The minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) were determined by broth microdilution. Serial twofold dilutions of TDS (Samin chemical, Co. Ltd., Gyeonggi-do, Korea) were prepared in the range of 0.001–4.000% (w/v). Each concentration of TDS (100 μL) was transferred into a 96-well plate filled with 100 μL of TSB (Oxoid). Each microorganism (10 μL) was then inoculated in each well. The final concentration of each microorganism was approximately 6 log CFU/mL. The 96-well plates were incubated at 37°C for 24 h. The MIC was determined at the lowest concentration of TDS did not allow visible growth of microorganisms. A 10 μL aliquot of broth from the wells was plated onto tryptic soya agar (TSA; Oxoid), and MBC was determined at the lowest concentration of TDS that produced no colonies on the TSA. All experiments were performed in triplicate.

Preparation of TDS solution

After inoculation, each concentration of TDS solution (0, 0.1, 0.5, 1, and 2%) was added into a sterilized bag. Sterile distilled water was used as TDS 0%, which was a control. The TDS was dissolved in 30% ethanol and the concentrations were varied from 0 to 2%. One hundred microliter of TDS was added to the tofu directly, and then massaged for 15 s to distribute the TDS into the sample. Samples were stored at 5 and 25°C for 5 days.

Microbial analysis

TDS-treated tofu samples were diluted with 90 mL of 0.85% saline (8.5 g/L sodium chloride; Sigma–Aldrich, St. Louis, USA) and homogenized using a stomacher (Laboratory Blender Stomacher 400; Seward, MO, USA) for 2 min. One-milliliter samples were serially diluted in saline, and then 100 µL of each dilution was plated on each selective media: eosin methylene blue (EMB; Oxoid), xylose lysine deoxycholate (XLD; Oxoid), oxford agar base (Oxoid) with antimicrobial supplement (Listeria selective supplement; Oxoid), and mannitol egg yolk polymyxin agar (MYP; Oxoid) were used as selective mediums for the enumeration of *E. coli* O157:H7, *S. Typhimurium*, *L. monocytogenes*, and *B. cereus*, respectively. The plates were incubated at 37 °C for 48 h. Countable colonies were expressed by log CFU/g.

Evaluation of sensory characteristics

Sensory qualities, such as color, odor, and overall acceptability of the tofu after TDS treatment were evaluated after storage at 5 °C for 5 days. Sensory evaluations were performed with 10 trained panels. The panelists scored overall liking of each sample using a 5-point hedonic scale, from 1 (representing inferiority) to 5 (representing excellence). After evaluating each sample, the panelists rinsed their mouth with water [25]. Sensory qualities were compared with those of sterile distilled water-treated tofu and analyzed using a statistical analysis system (SAS, version 9.4, SAS institute, Cary, NC, USA).

Statistical analysis

Three independent experiments were conducted and analyzed using the SAS version 9.4 (SAS Institute) to perform data analysis. Average values and significance were analyzed using Duncan's multiple range test. Significant differences were determined by $p < 0.05$.

Results and discussion

TDS showed antimicrobial effects against *E. coli* O157:H7, *S. Typhimurium*, *L. monocytogenes*, and *B. cereus* (data not shown). The MIC of TDS against *E. coli* O157:H7, *S. Typhimurium*, *L. monocytogenes*, and *B. cereus* were 1, 0.5, 0.25, and 0.25%, respectively. The MBC of TDS against *E. coli* O157:H7, *S. Typhimurium*, *L. monocytogenes*, and *B. cereus* were 2, 1, 0.5 and 0.25%, respectively. For all tested microorganisms, the MIC for TDS ranged from 0.25 to 1%(w/v), while the MBC ranged from 0.25 to 2%(w/v). The antimicrobial activity of TDS against

L. monocytogenes and *B. cereus* was higher than that against *E. coli* O157:H7 and *S. Typhimurium*. Based on our results, the final concentrations of TDS to be applied to tofu were determined to be 0.1, 0.5, 1, and 2%.

Tables 1, 2, 3 and 4 indicate the reduction of *E. coli* O157:H7, *S. Typhimurium*, *L. monocytogenes*, and *B. cereus* in tofu after treatment with TDS during storage at 5 °C and 25 °C for 5 days. Microbial counts of each pathogen were significantly ($p < 0.05$) different between the treatment samples of TDS and sterile distilled water control. During storage at 5 °C, treatment with 2% TDS reduced the levels of *E. coli* O157:H7, *S. Typhimurium*, *L. monocytogenes*, and *B. cereus* by 0.29, 0.34, 0.70, and 1.47 log CFU/g, respectively. However, the population of each pathogen increased during storage at 25 °C. Nevertheless, treatment with 2% TDS resulted in a growth inhibitory effect relative to that of untreated tofu. At 25 °C, treatment with 2% TDS showed lower levels of *E. coli* O157:H7, *S. Typhimurium*, *L. monocytogenes*, and *B. cereus* by 0.34, 0.90, 1.34, and 1.29 log CFU/g, respectively after 5 days. Overall, a higher concentration of TDS resulted in greater inhibition of the pathogens in tofu. In particular, isolated *B. cereus* from tofu, reported as one of the major spoilage microorganisms [4, 5], was more susceptible to TDS than *E. coli* O157:H7, *S. Typhimurium*, and *L. monocytogenes*. Kim et al. [18] noted that TDS inhibits microbial growth and has antimicrobial activity against microorganisms. They reported that TDS is more effective against Gram-positive bacteria such as *Staphylococcus aureus* than Gram-negative bacteria such as *E. coli* O157:H7. Therefore, TDS appears to be useful as an effective antimicrobial for inactivating microorganisms, particularly Gram-positive bacteria.

The addition of TDS to food commonly inhibits microbial growth. Choi et al. [20] found that 2% TDS in custard cream stored at 25 °C for 5 days reduced *E. coli* O157:H7, *S. Typhimurium* and *L. monocytogenes* by 2.43, 2.37, and 0.93 log CFU/g, respectively. They noted that the reduction increased in these pathogens as the concentration of TDS, storage temperature, and storage time were increased. Wei et al. [19] found that TDS has preservative activity in sterilized milk and apple juice. Fransisca and Feng [21] concluded that *E. coli* O157:H7 in alfalfa, broccoli, and radish seeds were reduced by 2.17, 0.99, and 0.38 log CFU/g when 1% TDS was added. Zhang et al. [26] reported that 0.5 and 1% TDS were effective in reducing the number of *E. coli* O157:H7 in vitro study. They suggested that TDS can be used to wash vegetables, instead of chlorine, to eliminate microorganisms.

In addition, the synergistic effect of TDS in combination with other chemicals has been reported by many researchers. Lee and Ha [22] reported that TDS, in combination with different commercial sanitizers, such as

Table 1 Population of *E. coli* O157:H7 in tofu after treatment with each concentration of TDS stored at 5 and 25 °C for 5 days

Reduction treatment	Population ¹ (log CFU/g) by storage days (at each temperature)					
	0 Day		1 Day		3 Days	
			5 °C		25 °C	
Control ²	6.05 ± 0.10 A ³	6.19 ± 0.10 Aa ⁴	9.53 ± 0.04 Aa	6.23 ± 0.03 Aa	8.94 ± 0.02 Ab	9.33 ± 0.03 Ac
0.1% TDS	5.97 ± 0.17 A	6.11 ± 0.09 Aab	8.91 ± 0.30 Ba	6.16 ± 0.14 ABab	8.94 ± 0.04 Aa	9.31 ± 0.01 Ab
0.5% TDS	6.03 ± 0.25 A	6.19 ± 0.10 Aa	8.85 ± 0.11 Ba	6.02 ± 0.11 BCa	8.83 ± 0.03 Bb	9.27 ± 0.03 Ab
1% TDS	6.06 ± 0.04 A	6.16 ± 0.07 Aa	8.83 ± 0.16 Ba	5.98 ± 0.08 BCb	8.81 ± 0.02 BCa	9.17 ± 0.06 Bb
2% TDS	5.88 ± 0.17 A	6.11 ± 0.03 Aa	8.94 ± 0.21 Bab	5.92 ± 0.06 Cab	8.76 ± 0.05 Ca	8.97 ± 0.06 Cb

¹Means ± standard deviations from triplicates²Treated with sterile distilled water³Means with the same uppercase letter in the same column are not significantly different ($p > 0.05$) at each temperature⁴Means with the same lowercase letter in the same row are not significantly different ($p > 0.05$) at each temperature**Table 2** Population of *S. Typhimurium* in tofu after treatment with each concentration of TDS stored at 5 and 25 °C for 5 days

Reduction treatment	Population ¹ (log CFU/g) by storage days (at each temperature)					
	0 Day		1 Day		3 Days	
			5 °C		25 °C	
Control ²	6.20 ± 0.15 A ³	5.95 ± 0.17 Aab ⁴	8.73 ± 0.07 ABa	5.98 ± 0.31 Aab	9.17 ± 0.12 Ab	9.27 ± 0.04 Ab
0.1% TDS	6.21 ± 0.03 A	5.95 ± 0.12 Aa	9.01 ± 0.05 Aa	5.86 ± 0.07 Aa	8.94 ± 0.02 Ba	8.17 ± 0.08 Ba
0.5% TDS	6.19 ± 0.04 A	5.94 ± 0.07 Aa	8.52 ± 0.07 Ba	5.98 ± 0.09 Aab	8.39 ± 0.38 Ba	8.20 ± 0.03 Ba
1% TDS	6.20 ± 0.10 A	6.16 ± 0.18 Aa	8.54 ± 0.25 Ba	5.85 ± 0.13 Aab	8.22 ± 0.25 Ba	8.50 ± 0.65 Ba
2% TDS	6.16 ± 0.12 A	6.10 ± 0.03 Aa	8.05 ± 0.08 Ca	5.75 ± 0.05 Ab	8.10 ± 0.02 Ba	8.37 ± 0.04 Bb

¹Means ± standard deviations from triplicates²Treated with sterile distilled water³Means with the same uppercase letter in the same column are not significantly different ($p > 0.05$) at each temperature⁴Means with the same lowercase letter in the same row are not significantly different ($p > 0.05$) at each temperature

Table 3 Population of *L. monocytogenes* in tofu after treatment with each concentration of TDS stored at 5 and 25 °C for 5 days

Reduction treatment	Population ¹ (log CFU/g) by storage days (at each temperature)					
	0 Day		1 Day		3 Days	
			5 °C		5 °C	
Control ²	6.63 ± 0.14 A ³		6.55 ± 0.01 Aa ⁴	8.51 ± 0.23 Aab	6.60 ± 0.01 Aa	8.39 ± 0.08 Aa
0.1% TDS	6.61 ± 0.14 A		6.49 ± 0.07 Aa	8.38 ± 0.26 Aa	6.66 ± 0.10 Aa	8.56 ± 0.10 Aa
0.5% TDS	6.68 ± 0.07 A		6.44 ± 0.07 Aa	8.64 ± 0.04 Aa	6.29 ± 0.14 Ba	8.35 ± 0.06 Ab
1% TDS	6.59 ± 0.06 A		6.44 ± 0.04 Aa	8.54 ± 0.02 Aa	6.20 ± 0.20 BCa	8.42 ± 0.20 Aa
2% TDS	6.58 ± 0.12 A		6.22 ± 0.01 Ba	7.98 ± 0.19 Ba	6.02 ± 0.05 Cb	7.64 ± 0.19 Bab

¹Means ± standard deviations from triplicates²Treated with sterile distilled water³Means with the same uppercase letter in the same column are not significantly different ($p > 0.05$) at each temperature⁴Means with the same lowercase letter in the same row are not significantly different ($p > 0.05$) at each temperature**Table 4** Population of *B. cereus* in tofu after treatment with each concentration of TDS stored at 5 and 25 °C for 5 days

Reduction treatment	Population ¹ (log CFU/g) by storage days (at each temperature)					
	0 Day		1 Day		3 Days	
			5 °C		5 °C	
Control ²	4.24 ± 0.34 A ³		4.34 ± 0.31 Aa ⁴	8.09 ± 0.17 Aa	4.36 ± 0.51 Aa	7.98 ± 0.15 ABa
0.1% TDS	4.40 ± 0.35 A		4.25 ± 0.10 Aa	7.90 ± 0.09 ABa	4.12 ± 0.12 ABa	8.25 ± 0.13 Aa
0.5% TDS	3.65 ± 0.63 A		4.24 ± 0.30 Aa	7.92 ± 0.22 ABa	3.75 ± 0.21 BCa	7.54 ± 0.09 Ca
1% TDS	4.05 ± 0.13 A		3.95 ± 0.18 ABa	7.59 ± 0.27 BCa	3.80 ± 0.10 BCab	7.63 ± 0.19 Ca
2% TDS	3.65 ± 0.75 A		3.60 ± 0.12 Ba	7.44 ± 0.14 Ca	3.50 ± 0.18 Cab	7.81 ± 0.16 BCb

¹Means ± standard deviations from triplicates²Treated with sterile distilled water³Means with the same uppercase letter in the same column are not significantly different ($p > 0.05$) at each temperature⁴Means with the same lowercase letter in the same row are not significantly different ($p > 0.05$) at each temperature

Table 5 Sensory evaluation (color, odor, and overall acceptability) of tofu treated with TDS stored at 5 °C for 5 days

Sensory characteristics	Treatment	0 Day	1 Day	3 Days	5 Days
Color	Control ¹	4.90 ± 0.32 a	4.60 ± 0.70 a	4.70 ± 0.67 a	4.50 ± 1.08 a
	0.1% TDS	4.90 ± 0.32 a	4.50 ± 0.71 a	4.70 ± 0.67 a	4.30 ± 1.06 a
	0.5% TDS	4.70 ± 0.48 a	4.40 ± 0.84 a	4.70 ± 0.67 a	4.50 ± 0.71 a
	1% TDS	4.90 ± 0.32 a	4.40 ± 0.84 a	4.60 ± 0.70 a	4.50 ± 0.85 a
	2% TDS	4.80 ± 0.42 a	4.20 ± 0.79 ab	4.60 ± 0.84 ab	4.20 ± 1.03 ab
Odor	Control	4.67 ± 0.48 a	4.40 ± 0.97 a	4.20 ± 1.03 a	4.20 ± 1.14 a
	0.1% TDS	4.79 ± 0.42 a	4.20 ± 1.03 ab	4.30 ± 0.82 ab	3.90 ± 1.20 ab
	0.5% TDS	4.67 ± 0.48 a	4.20 ± 1.03 a	4.20 ± 0.79 a	3.70 ± 1.42 a
	1% TDS	4.56 ± 0.53 a	4.20 ± 0.79 ab	3.90 ± 0.74 ab	3.90 ± 0.88 ab
	2% TDS	4.33 ± 0.67 a	3.70 ± 1.16 a	4.00 ± 0.67 a	3.90 ± 0.88 a
Overall acceptability	Control	4.80 ± 0.42 a	4.30 ± 0.82 ab	4.30 ± 0.95 ab	4.10 ± 0.99 ab
	0.1% TDS	4.70 ± 0.48 a	4.50 ± 0.71 ab	4.50 ± 0.71 ab	4.00 ± 0.94 ab
	0.5% TDS	4.80 ± 0.42 a	4.50 ± 0.71 ab	4.30 ± 0.67 ab	3.90 ± 0.57 bc
	1% TDS	4.70 ± 0.48 a	4.30 ± 0.67 a	4.10 ± 0.57 ab	4.00 ± 0.47 ab
	2% TDS	4.40 ± 0.52 a	3.90 ± 0.99 a	4.20 ± 0.42 a	3.70 ± 0.82 ab

Means with the same lowercase letter in the same row are not significantly different ($p > 0.05$)

¹Treated with sterile distilled water

chlorine, calcium oxide, ethanol, hydrogen peroxide, and quaternary ammonium compounds, inactivates coliforms in rice synergistically. Oh et al. [23] reported that a combination of 100 mL/kg chlorine and 1000 mg/kg TDS reduced *L. monocytogenes* by 0.38 log CFU/g in chicken breast. Kim et al. [27] found that a combination of TDS and ethanol reduced the *B. cereus* load on fresh wet noodles more effectively than the treatment with ethanol only. According to Fransisca et al. [24], treatment with 10% malic acid and 1% TDS completely eliminated *E. coli* O157:H7 on alfalfa seeds.

Sensory evaluations of TDS-treated tofu stored at 5 °C for 5 days were performed at 0, 1, 3, and 5 days. Table 5 shows the results of color, odor, and overall acceptability analysis of tofu after TDS treatment. With respect to color properties, there was no significant ($p > 0.05$) difference between sterile distilled water-treated and TDS-treated tofu. The results of the odor analysis of TDS-treated tofu showed that as storage time increased, the odor score of TDS-treated tofu decreased, however, there was no significant ($p > 0.05$) difference. The overall acceptability of TDS-treated tofu also decreased relative to the control as storage time increased, but no significant ($p > 0.05$) difference was found. The overall sensory properties of TDS-treated tofu were not significantly different from those of sterile distilled water-treated tofu. Thus, this method is suitable for practical application of inactivating foodborne pathogens in tofu. Ha et al. [28] reported that treatment with TDS and NaOCl in head lettuce showed no significant ($p < 0.05$) differences in color, odor, taste, and overall acceptability. Lee and Ha [22] found that the sensory

properties of cooked rice treated with 1000 ppm TDS with 5000 ppm hydrogen peroxide, 100–800 ppm TDS with 100–200 ppm chlorine, or 800 ppm TDS with 100,000 ppm ethanol did not differ from those of water-treated cooked rice. Oh et al. [23] observed that 1000 mg/kg TDS and 100 mL/kg chlorine had no effect on the color and texture of chicken breast.

Our results, during storage for 5 days at 5 °C, indicate that the addition of 2% TDS significantly ($p < 0.05$) reduced the levels of *E. coli* O157:H7, *S. Typhimurium*, *L. monocytogenes*, and *B. cereus*. Specifically, more reduction was shown with *B. cereus*, which is frequently isolated from spoiled tofu. TDS is considered an effective antimicrobial agent in commercial tofu for preventing foodborne pathogen infection. Furthermore, TDS-treated samples did not differ in color, odor, and overall acceptability from those treated with sterile distilled water. Thus, TDS can be used to control pathogens in tofu and can be used in commercial tofu. However, the inactivation effect of TDS in combination with other antimicrobial agents may be more effective than that of TDS alone; therefore, further studies involving combined treatments are required.

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References

1. Préstamo G, Fontecha J. High pressure treatment on the tofu fatty acids and acylglycerols content. *Innovative Food Sci. Emerg. Technol.* 8: 188–191 (2007)
2. Ananchaipattana C, Hosotani Y, Kawasaki S, Pongswat S, Latiful BM, Isobe S, Inatsu Y. Bacterial contamination of soybean curd (tofu) sold in Thailand. *Food Sci. Technol. Res.* 18: 843–848 (2012)
3. Ashraf HR, White M, Klubek B. Microbiological survey of tofu sold in a rural Illinois county. *J. Food Protect.* 62: 1050–1053 (1999)
4. Joo G, Hur S, Choi Y, Rhee I. Characterization and identification of bacteria from putrefying soybean curd. *Korean J. Postharvest Sci. Technol.* 5: 292–298 (1998)
5. Nout M, Bakshi D, Sarkar P. Microbiological safety of kinema, a fermented soya bean food. *Food Control.* 9: 357–362 (1998)
6. Aulisio CC, Stanfield JT, Weagant SD, Hill WE. Yersiniosis associated with tofu consumption: serological, biochemical and pathogenicity studies of *Yersinia enterocolitica* isolates. *J. Food Protect.* 46: 226–230 (1983)
7. Tacket CO, Harris N, Allard J, Nolan C, Nissinen A, Quan T, Cohen ML. An outbreak of *Yersinia enterocolitica* infections caused by contaminated tofu (soybean curd). *Am. J. Epidemiol.* 121: 705–711 (1985)
8. Lee LA, Ostroff SM, McGee HB, Johnson DR, Downes FP, Cameron DN, Bean NH, Griffin PM. An outbreak of shigellosis at an outdoor music festival. *Am. J. Epidemiol.* 133: 608–615 (1991)
9. Padhye NV, Doyle MP. *Escherichia coli* O157: H7: epidemiology, pathogenesis, and methods for detection in food. *J. Food Protect.* 55: 555–565 (1992)
10. Karmali MA. Infection by verocytotoxin-producing *Escherichia coli*. *Clin. Microbiol. Rev.* 2: 15–38 (1989)
11. Wood RL, Pospischil A, Rose R. Distribution of persistent *Salmonella* Typhimurium infection in internal organs of swine. *Am. J. Vet. Res.* 50: 1015–1021 (1989)
12. Oliveira S, Rodenbusch C, Ce M, Rocha S, Canal C. Evaluation of selective and non-selective enrichment PCR procedures for *Salmonella* detection. *Lett. Appl. Microbiol.* 36: 217–221 (2003)
13. Rouquette C, Berche P. The pathogenesis of infection by *Listeria monocytogenes*. *Microbiologia (Madrid, Spain)* 12: 245–258 (1996)
14. Jalali M, Abedi D. Prevalence of *Listeria* species in food products in Isfahan, Iran. *Int. J. Food Microbiol.* 122: 336–340 (2008)
15. Adak G, Long S, O'Brien S. Trends in indigenous foodborne disease and deaths, England and Wales: 1992 to 2000. *Gut.* 51: 832–841 (2002)
16. Ross T, Dalgaard P, Tienungoon S. Predictive modelling of the growth and survival of *Listeria* in fishery products. *Int. J. Food Microbiol.* 62: 231–245 (2000)
17. Sutherland J, Bayliss A, Roberts T. Predictive modelling of growth of *Staphylococcus aureus*: the effects of temperature, pH and sodium chloride. *Int. J. Food Microbiol.* 21: 217–236 (1994)
18. Kim HS, Cho KH, Lee DK. A Study on the Antimicrobial Activity and Preservative Effect of Thiamine Dilauryl Sulfate in Cosmetics. *J. Korean Oil Chemists' Society.* 22 (2005)
19. Wei L, Cheng J, Meng Y, Ren Y, Deng H, Guo Y. A novel formulation of thiamine dilaurylsulphate and its preservative effect on apple juice and sterilised milk. *Food Chem.* 152: 415–422 (2014)
20. Choi MR, Jeong SG, Liu Q, Ban GH, Lee SY, Park JW, Kang DH. Effect of thiamine dilaurylsulfate against *Escherichia coli* O157: H7, *Salmonella* Typhimurium, *Listeria monocytogenes* and *Bacillus cereus* spores in custard cream. *LWT-Food Sci. Technol.* 60: 320–324 (2015)
21. Fransisca L, Feng H. Effect of surface roughness on inactivation of *Escherichia coli* O157: H7 87-23 by new organic acid–surfactant combinations on alfalfa, broccoli, and radish seeds. *J. Food Protect.* 75: 261–269 (2012)
22. Lee MJ, Ha S-D. Synergistic effect of vitamin B1 on sanitizer and disinfectant treatments for reduction of coliforms in rice. *Food Control.* 19: 113–118 (2008)
23. Oh SR, Park SY, Ha SD. Combined effects of chlorine and thiamine dilauryl sulfate on reduction of *Listeria monocytogenes* in chicken breast and development of predictive growth models. *Poultry. Sci.* 93: 1503–1510 (2014)
24. Fransisca L, Park HK, Feng H. *Escherichia coli* O157: H7 population reduction from alfalfa seeds with malic acid and thiamine dilauryl sulfate and quality evaluation of the resulting sprouts. *J. Food Sci.* 77: M121–M126 (2012)
25. Meilgaard MC, Carr BT, Civille GV. Sensory evaluation techniques. CRC Press, Boca Raton, Florida, USA (2006)
26. Zhang X, Fan X, Solaiman D, Ashby R, Liu Z, Mukhopadhyay S, Yan R. Inactivation of *Escherichia coli* O157: H7 in vitro and on the surface of spinach leaves by biobased antimicrobial surfactants. *Food Control.* 60: 158–165 (2016)
27. Kim BY, Lee JY, Ha SD. Growth characteristics and development of a predictive model for *Bacillus cereus* in fresh wet noodles with added ethanol and thiamine. *J. Food Protect.* 74: 658–664 (2011)
28. Ha JH, Lee JY, Chung MS, Park J, Ha S. Synergism of combined vitamin B1 and NaOCl treatment for the reduction of microbiological contamination in head lettuce. *J. Food Process. Preserv.* 37: 86–92 (2013)