Efficacy of Neutral Electrolyzed Water, Quaternary Ammonium and Lactic Acid Based Solutions in Controlling Microbial Contamination of Food Cutting Boards

Hamzah M. Al-Qadiri, Mahmoudreza Ovissipour, Setareh Ghorban Shiroodi, Byju N. Govindan, Nivin Al-Alami, Barbara Rasco

*a School of Food Science, Washington State University, Pullman, WA 99164, USA
b Department of Biological Systems Engineering, Washington State University, Pullman, WA 99164, USA
c Water, Energy and Environment Center, The University of Jordan, Amman 11942 Jordan

Running Title: Efficacy of Neutral Electrolyzed Water, Quaternary Ammonium and Lactic Acid Based Solutions in Controlling Microbial Contamination of Food Cutting Boards

*Corresponding author. Tel: +1 509 335 3843; Fax: +1 509 335 4815.

E-mail address: alqadiri@wsu.edu (H.M. Al-Qadiri)
Abstract

Bactericidal activity of neutral electrolyzed water (NEW), quaternary ammonium (QUAT), and lactic acid based solutions was investigated at ambient temperature against Salmonella Typhimurium, Escherichia coli O157:H7, Campylobacter jejuni, Listeria monocytogenes and Staphylococcus aureus that were inoculated onto the surface of scarred polypropylene and wooden food cutting boards. Antimicrobial activity was also examined when using cutting boards in preparation of raw chopped beef, chicken tenders or salmon fillet. Viable counts of survivors were determined as log CFU/100 cm\(^2\) within 0 (untreated control), 1, 3 and 5 min of treatment. Within the first minute of treatment, NEW and QUAT solutions caused more than 3 log bacterial reductions on polypropylene surfaces whereas less than 3 log reductions were achieved on wooden surfaces. After 5 min of treatment, more than 5 log reductions were achieved in all bacterial strains inoculated onto polypropylene surfaces. Using NEW and QUAT solutions within 5 min reduced Gram-negative bacteria by 4.58-4.85 log compared to more than 5 log reductions in Gram-positive bacteria inoculated onto wooden surfaces. Lactic acid treatment was significantly less effective (\(P < 0.5\)) compared to NEW and QUAT treatments. However, a considerable decline in antimicrobial effectiveness was observed when both cutting board types were used to prepared raw meat.

Keywords: Neutral electrolyzed water, quaternary ammonium, lactic acid, cutting boards.

Practical Application

NEW could be used as an effective alternative to commonly used chemical sanitizers such as QUATS. Treatments effectiveness against microbial contamination was higher on polypropylene compared to wooden surfaces.
Introduction

Contamination, growth and survival of pathogenic bacteria during food preparation may cause several foodborne outbreaks which may impose significant health and economical threats. During the past decade, increasing industrialization and urban living caused considerable changes in eating habits with increased sales of ready-to-eat meals in which processed food has become more vulnerable to bacterial contamination (Taylor and others 1999; Adams and Motarjemi 1999; Langsrud and others 2003; Moretro and others 2011). Accordingly, any breakdown in food hygiene during meals preparation in restaurants and high-volume food processing facilities may result in more people to be affected, spending millions of dollars due to medical expenses and decrease in employee productivity (Adams and Motarjemi 1999; Monnin and others 2012).

The equipment and utensils used in food preparation may act as a major source of bacterial contamination, for instance, knives and cutting boards used with uncooked products such as raw meat or poultry may contaminate cooked or ready-to-eat products, particularly if they are used without being adequately cleaned and disinfected. Plastic and wooden made cutting boards are considered as a major vehicle for bacterial cross contamination, particularly with deep cracks and scars on the surface that may provide a suitable environment for bacteria to survive (Goh and others 2014). Sanitizing with chemical agents is the most common and economical method to reduce bacterial count to levels considered safe. Food contact sanitizers, which are used in food processing, handling, preparation and service industry, are mainly used on surfaces that are normally come in contact with food products and should only be applied to cleaned surfaces (Gaulin and others 2011; U.S. Department of Agriculture 2013). However, in order to be authorized with disinfectant claims, food contact sanitizers must reduce microbial contamination by 5-log at 20 °C (U.S. Environmental Protection Agency 1999; U.S. Food and Drug Administration 2009; Gaulin and others 2011; U.S.
Department of Agriculture 2013). Additionally, approved food sanitizers must be safe for use on food
contact surfaces, do not require a rinse after the sanitizing step (rated by the USDA as D2 sanitizers),
free of dyes and fragrances and EPA registered for sanitizing food contact surfaces (U.S.
Environmental Protection Agency 1999; U.S. Food and Drug Administration 2009; Gaulin and others

There are numerous commercial sanitizers that are approved to be used in food premises and
which may contain chlorine compounds, peroxide mixtures, quaternary ammonium compounds
(QUATS), acid anionic, hydrogen peroxide and iodine (Marriott 2006; U.S. Food and Drug
Administration 2009; Fraser and Pascall 2010; Gaulin and others 2011). Chlorine based sanitizers are
the most commonly used by the food service industry for many reasons; they are effective on a wide
variety of microorganisms, generally inexpensive, and considered the easiest sanitizers to prepare and
test with relatively stable efficacy (Fraser and Pascall 2010; Gaulin and others 2011; Monnin and
others 2012). However, chlorine based sanitizers are corrosive and may form toxic chlorine
byproducts if they applied at higher concentrations, and their bactericidal activity reduces in the
presence of organic matter (Fawell 2000; Fraser and Pascall 2010; Gaulin and others 2011; Monnin
and others 2012). QUATS based sanitizers are widely used as bactericidal agents in medical and food
environments in which they are generally applied at 200 mg/L (Pfuntnner 2011). They are colorless,
odorless, nontoxic, noncorrosive, nonirritating, stable at high temperature, active over a wide pH
range, and relatively remain effective in the presence of organic materials (Sundheim and others
1998; Fraser and Pascall 2010; Pfuntnner 2011). QUATS are slow-acting against some
microorganisms and they are more effective against Gram-positive bacteria with limited activity
against Gram-negative bacteria (Gaulin and others 2011). Organic acids are generally recognized as
safe (GRAS) antimicrobial agents, they could be used in a concentration of 1-3% without an effect
on food quality attributes (Raftari and others 2009). Organic acids, such as lactic acid, have been approved by the Food Safety and Inspection Service of the United States Department of Agriculture to be applied as antibacterial agents against different types of pathogenic bacteria and to inhibit spoilage in food products (Skrivanova and others 2011; Lingham and others 2012).

Due to its antimicrobial properties, electrolyzed water (EW) has been applied to control bacterial contamination on food products, non-food contact surfaces, and food processing surfaces, including the equipment and utensils used in food preparation (Venkitanarayanan and others 1999; Deza and others 2007; Hricova and others 2008; Fraser and Pascall 2010; Monnin and others 2012). However, in addition to its advantages of reducing equipment corrosiveness and minimizing skin and mucous irritation, using of neutral EW (NEW) that combines both acidic and basic EW may optimize bactericidal effect due to the increase in penetration rate of NEW water through bacterial cell membranes, its high oxidation reduction potential, availability of chlorine with the presence of OH⁻ as an active surfactant, and its longer storage life at neutral pH which reduces chlorine loss (Len and others 2002; Monnin and others 2012).

The significance of this study was to investigate the bactericidal activity of neutral electrolyzed water, quaternary ammonium, and lactic acid based solutions against Salmonella Typhimurium, Escherichia coli O157:H7, Campylobacter jejuni, Listeria monocytogenes and Staphylococcus aureus that were inoculated onto the surface of scarred polypropylene and wooden food cutting boards. The study also examined the antimicrobial activity when using cutting boards in preparation of raw chopped beef, chicken tenders or salmon fillet.

Materials and Methods
**Bacterial strains and inoculum preparation**

All bacterial American Type Culture Collection (ATCC) strains were obtained from Microbiologics, Inc. (St. Cloud, MN). *S. Typhimurium* ATCC 13311, *E. coli* O157:H7 ATCC 43888, *L. monocytogenes* ATCC 19112 and *S. aureus* ATCC 29213 were individually cultured and activated by inoculating each specific Kwik-Stik swab (Microbiologics, Inc.) into 50 mL of tryptic soy broth (TSB) (Bacto™) and then were incubated at 37°C for 24 h. All strains were cultured to yield a cell count of approximately $10^9$ CFU/mL. Bacterial suspensions were enumerated in duplicate using the spread-plate technique in which a 1-mL aliquot of each dilution was divided into 5 aliquots of 0.2 mL and cultured on tryptic soy agar TSA (Bacto™). *C. jejuni* ATCC 29428 was activated by inoculating the Kwik-Stik swab into 50 mL of Campylobacter enrichment broth consisting of Campylobacter nutrient broth no. 2 (CM0067, Oxoid Ltd.) and supplemented with Campylobacter growth supplement (SR0232E, Oxoid Ltd.). *C. jejuni* broth was then incubated in an anaerobic jar at 37°C for 48 h under a microaerophilic atmosphere (~ 6 to 7% O₂) using CampyGen sachets (CN0025, Oxoid Ltd.) (Al-Qadiri and others 2015). *C. jejuni* was cultured to obtain a cell count of approximately $10^9$ CFU/mL, it was enumerated in duplicate using the spread-plate technique and cultured on Campylobacter blood-free medium (modified CCDA Preston, CM0739, Oxoid Ltd.) (Astorga and Alonso 2010; Al-Qadiri and others 2015).

After the appropriate incubation of bacterial cultures, 50 mL broth of each strain was transferred under aseptic conditions to a sterile centrifuge tube and centrifuged for 15 min at 5000 rpm ($3380 \times g$) to harvest bacterial cells (AccuSpin centrifuge, Thermo Fisher Scientific, Waltham, MA). To eliminate any effect of broth components and bacterial metabolites, the resultant pellets were resuspended in 50 mL of sterile saline solution (0.85 %; wt/vol NaCl). The tubes were then centrifuged as before, and the resulting pellets of the five strains were then resuspended in 50-mL
aliquots and centrifuged for a second time as described above. The supernatant was decanted and the
resulting washed pellets were resuspended in sterile 10-mL aliquots, which were then used to
inoculate the surfaces of the cutting boards. To prepare the approximate cell suspension inocula of
each strain, culturing schemes for bacterial cells were based upon separate experiments in which the
approximate cell inocula for the five bacterial strains were preliminary determined.

**Cutting boards and inoculation process**

Polypropylene and maple-hardwood cutting boards were used in this study to examine the
antibacterial activity profiles. To simulate normal usage, the entire one surface of each cutting board
was scarred by metal grater then by kitchen pizza-cutter (50 times in cross sectional directions), the
surface was then sharply marked into squares (10 x 10 cm² each). The boards were thoroughly rinsed
with sterile deionized water and sprayed with 70% ethyl alcohol. The polypropylene cutting boards
were wrapped in aluminum foil and sterilized by autoclaving at 121 °C for 20 min. The wooden
cutting boards were placed in boiling water for 30 min and then aseptically wrapped using sterile
aluminum foil sheets. Swabbing of these cutting boards showed no bacterial recovery prior to each
experimental trial.

On each cutting board surface, a volume of 5 mL of the previously prepared bacterial culture
(approximately 10⁹ CFU/mL) was applied separately at ambient temperature (22 °C) and evenly
spread over the entire surface using a sterile wet cotton swab. Following inoculation process, the
cutting boards were dried under aseptic conditions in a laminar flow hood for 30 min at ambient
temperature. Another group of the cutting boards was used to separately prepare raw chopped beef,
chicken tenders or salmon fillet. Prepackaged raw beef, chicken and salmon portions were purchased
from a local retail store and kept at 4 °C overnight. No preparation of washing, removal of fat or skin
tissue was undertaken before processing. Two pounds of meat samples were prepared using a kitchen
knife, meat pieces were rubbed several times over the surface of each cutting board, processing time was within 10-15 min. Meat pieces were then removed and the cutting boards with meat juices were air dried under a laminar flow hood for 1 h at ambient temperature to simulate the normal use in food service establishments.

The initial viable bacterial load on the inoculated air-dried surfaces was determined by swabbing two squares (the corner plus the middle, 100 cm² each) using individual sterile wet cotton swabs that were previously prepared in a 5 mL sterile D/E Neutralizing Broth (Difco™). The swabs were washed and 1 mL of appropriate dilutions was enumerated in duplicate using the spread-plate technique. A 1-mL aliquot was divided into 5 aliquots of 0.2 mL and cultured on tryptic soy agar TSA (Bacto™) or Campylobacter blood-free medium as described above. The mean viable bacterial counts were determined as log CFU/100 cm². For cutting boards that had been used to prepare meat pieces, the initial viable count was determined as above, however, swabbing was performed after rinsing the surfaces with sterile deionized water to remove any organic residues followed by air drying for 30 min as described below. TSA (Bacto™) was used to determine total viable counts (log CFU/100 cm²), plates were incubated at 37 °C and examined for 72 h.

**Preparation of treatment solutions**

Three antimicrobial treatments were prepared: neutral electrolyzed water (NEW), quaternary ammonium (QUAT) and lactic acid based solutions. A commercial NEW (Aquaox Disinfectant 275) was provided from Aquaox Industries Inc. Fontana, CA 92336. The active ingredient of the Aquaox NEW stock solution is hypochlorous acid (0.0275%) that is generated electrochemically by electrolysis of a dilute sodium chloride solution passing through an electrolytic cell at neutral pH. For the treatment of cutting boards, Aquaox NEW was diluted in sterile deionized water to obtain a final free available chlorine (FAC) content of 200 mg/L, a pH of 6.6 and an oxidation-reduction potential
(ORP) of 805 mV. Treatment solution was kept refrigerated and used within 3 h of preparation. The pH, ORP and FAC content were measured by a pH meter (FE20, Mettler-Toledo, Columbus, OH, USA), a pocket sized redox meter (HI 98201, HANNA® Instruments, Ann Arbor, Michigan, USA) and a digital colorimeter (Colorimeter™ Analysis System, Hach Co., Loveland, CO, USA), respectively, according to the manufacturer instructions. A commercial EPA registered D2 classified QUAT based antimicrobial solution was used as a second treatment option. The active ingredients of the QUAT stock solution are 5% as alkyl (60% C\textsubscript{14}, 30% C\textsubscript{16}, 5% C\textsubscript{12}, 5% C\textsubscript{18}) dimethyl benzyl ammonium chlorides and 5% as alkyl (68% C\textsubscript{12}, 32% C\textsubscript{14}) ethylbenzyl ammonium chlorides. For the treatment of cutting boards, QUAT stock solution was diluted in sterile deionized water according to manufacturer instructions to obtain a final active QUAT solution of 200 mg/L. As a third treatment solution, a commercial household lactic acid based antibacterial detergent was used in which L-Lactic acid (2%) is the main active antibacterial ingredient (98% as inert ingredients). The treatment solution was prepared according to the manufacturer instructions by diluting 100 mL detergent in 2 L sterile deionized water.

**Sanitization treatment and microbial recovery**

For cutting boards that were inoculated with bacterial strains, each air-dried surface was entirely sprayed three times within 30 seconds (from top to bottom and from right to left) with 30 mL of the previously prepared NEW, QUAT, or lactic acid based solutions at ambient temperature. For cutting boards that had been used to prepare meat pieces, they were aseptically rinsed with a sterile 1 L deionised water (using a sterile stainless tray) to remove any organic residues followed by air drying under aseptic conditions in a laminar flow hood for 30 min at ambient temperature. After drying, they were sprayed with 30 mL treatment solutions as described above.
To recover surviving bacteria, viable bacterial counts were determined within 1, 3 and 5 min as treatment time intervals. Two squares (100 cm\(^2\) each) were individually selected for each time interval and swabbed by using separate sterile wet cotton swabs that were previously prepared in a 5 mL sterile D/E Neutralizing Broth (Difco™). Each square was swabbed in three directions, vertical, horizontal and diagonal. The swabs were then washed and 1 mL of the homogenized suspension was serially diluted (dilution range: \(10^0\) to \(10^{-4}\)) in 9 mL of sterile 0.1% peptone water (Bacto™). Samples were examined in duplicate using the spread-plate technique. A 1-mL aliquot of each dilution was divided into 5 aliquots of 0.2 mL, which then they were evenly spread on TSA (Bacto™) for enumeration of S. Typhimurium, E. coli O157:H7, L. monocytogenes and S. aureus (Al-Qadiri and others 2006, 2008). Plates were then incubated at 37°C for 24-48 h. Campylobacter blood-free medium (modified CCDA Preston, CM0739, Oxoid Ltd.) was used to enumerate surviving C. jejuni (Astorga and Alonso, 2010). Plates were incubated at 37 °C for 48 h under microaerophilic conditions. The mean viable bacterial counts were determined as log CFU/100 cm\(^2\). TSA (Bacto™) was used to recover surviving microorganisms on treated surfaces used to prepare meat pieces in which microbial swabbing was performed as above (dilution range: \(10^0\) to \(10^{-2}\)). Plates were incubated at 37°C and examined for 72 h. The mean viable counts were determined as log CFU/100 cm\(^2\). Surfaces that were not treated with antimicrobial solutions served as controls (baseline reading). All tests were carried out in triplicate.

Statistical analysis

The experiment consisted of three independent replicate trials (\(n = 3\)) and each reported value is the mean viable count ± standard error (SE) of the results of three replicate treatments per experimental trial. An analysis of variance, using the mixed-effects procedure for bacterial counts, was conducted with SAS software (SAS Institute, 2011). Polypropylene or wood, treatment solution,
and treatment time were treated as fixed effects. Subjects were random samples from the target population and, therefore, were treated as random effects in the model. The interaction among fixed-effect variables was analyzed. The Kenward and Roger method was used to evaluate the denominator degrees of freedom (Kenwardroger = DDFM). In order to adjust the estimated standard deviations for fixed effects and interaction effects (Littell et al., 2006), the level of significance was set at a $P$ value of $< 0.05$. Post hoc multiple pairwise comparisons of treatment group means were performed with the Tukey-Kramer adjustment (Tukey’s honestly significant difference test) to control the type I error rate.

**Results and Discussion**

Microbial contamination of cutting boards used in food preparation may pose a health threat of causing foodborne illnesses when sanitizing procedures are not applied efficiently. Different chemical sanitizers are used to reduce microbial loads on cutting boards surfaces; however, several factors may restrict their applications. Limitations may include effective concentration to be applied, contact time, active ingredients, residual effect, formation of toxic byproducts, type of microorganisms present and nature of organic and inorganic residues on the surface (Fraser and Pascall 2010). For the current study, it might be the first in investigation with comparison the antimicrobial activity of NEW, QUAT and lactic acid based formulations against microbial contamination of laboratory inoculated scarred polypropylene and wooden cutting boards surfaces at ambient temperature. As shown in Tables 1 and 2, NEW and QUAT treatments showed a broad spectrum of action over the studied bacterial strains. There were significant differences ($P < 0.05$) in bacterial reductions with regard to contact time and which maximized after 5 min of treatment. Within the first minute of treatment, NEW and QUAT solutions caused more than 3 log/100 cm$^2$ bacterial reductions on polypropylene surfaces whereas less than 3 log reductions were achieved on wooden
surfaces. After 5 min of treatment, more than 5 log reductions were achieved in all bacterial strains inoculated onto polypropylene surfaces, however, Gram (+) bacteria were more sensitive to both antimicrobial solutions. Using NEW and QUAT solutions within 5 min reduced Gram-negative bacteria by 4.58-4.85 log compared to more than 5 log reductions in Gram-positive bacteria inoculated onto wooden surfaces. Obviously, there was no significant difference ($P > 0.05$) between NEW and QUAT treatments on both cutting board surfaces; however, treatment effectiveness against inoculated bacteria was higher on polypropylene compared to wooden surfaces.

Our findings are consistent with a previous study reported that rinsing of contaminated cutting boards in either NEW or sodium hypochlorite NaClO solutions (~64 mg/L) revealed no significant differences between the final populations of each bacterial strain with regard to the treatment solutions, however, a significant difference was found between the decontamination of plastic and wooden surfaces. In plastic boards, the initial bacterial populations decreased by approximately 5.4 log CFU/50 cm$^2$ after 1 min, however, in wooden boards the initial bacterial populations reduced by 2.5 log, and when the rinsing time was increased to 5 min, populations were reduced by about 4 log (Deza and others 2007). In a study performed to investigate bacterial retention and cleanability of plastic and wooden cutting boards, it was revealed that wooden boards could absorb bacterial suspension in which the inner part of the wood might still remain wet and retain most of the bacteria although the surface appeared dry (Welkers and others 1997).

As sanitizers, QUATS are commonly applied at 200 mg/L to food contact surfaces, the solution is allowed to dry in which a residual effect may remain and provide antimicrobial activity until degradation occurs (Pfuntner 2011). The germicidal activity of QUATS is mainly due to the binding of the positively charged cations with the acidic phospholipids in the microbial cell membrane to block the transportation of nutrients and discharge of waste into and out of the
cytoplasm (Block 2001; McBain and others 2004). In this study, we found that QUAT solution was more effective against *L. monocytogenes* and *S. aureus* compared to Gram-negative bacteria. Although QUAT formulations are effective against a wide range of microbes, it was revealed that their antimicrobial action is more effective against Gram-positive bacteria (Block 2001; McBain and others 2004; Pfuntner 2011). It was reported that QUATS are more effective against *L. monocytogenes* with limited effectiveness against most Gram-negative bacteria except *Salmonella* spp. and *E. coli* (Holah and others 2002; Gaulin and others 2011).

Lactic acid treatment was significantly less effective (*P* < 0.5) compared to NEW and QUAT treatments. As shown in Tables 1 and 2, less than 2 log reductions were achieved within the first minute of treatment. As found above, lactic acid was more effective against inoculated bacteria on polypropylene surfaces, the highest log reductions achieved after 5 min were 2.2-2.75 and 1.9-2.45 log/100 cm² for polypropylene and wooden surfaces, respectively, and in which bacterial inhibition was more effective against Gram-positive bacteria. L-(+)-Lactic acid is known as 2-hydroxypropanoic acid, which is a GRAS organic acid belonging to carboxylic acids family (U.S. Environmental Protection Agency 2009). Lactic acid has a relatively limited antimicrobial efficacy; the undissociated form passively diffuses into the cytoplasm causes internal pH to decrease, protein denaturation, and disruption of proton motive force (Cherrington and others 1990; Culver and others 2014). The relative sensitivity of Gram-positive bacteria to lactic acid could be linked to the structure of the cell wall which does not possess an outer membrane, which as a result may decrease intrinsic resistance against organic acids (Raftari and others 2009). Lactic acid solutions are widely used as general decontaminants to control microbial contamination in meat carcass and minimally processed produce (Barboza and others 2002; Raftari and others 2009; Sagong and others 2011). In a previous study, 0.5% lactic acid was used for 2 min to reduce microbial contamination in iceberg lettuce in
which *E. coli* and *L. monocytogenes* were reduced by 2.7 and 2.0 log CFU/g, respectively. However, treatment at 1% for 5 min only raised decontamination efficacy to 3.0 and 2.2 log CFU/g, respectively (Akbas and Olmez 2007). Sasong and others (2011) reported that washing of iceberg lettuce with 1% lactic acid for 5 min decreased bacterial counts of *E. coli* O157:H7, *Salmonella* Typhimurium, and *L. monocytogenes* by 1.45, 139, and 1.17 log CFU/g, respectively.

To simulate normal application, the three antimicrobial solutions were used at the same concentrations and time intervals to reduce microbial counts on cutting board surfaces that had been used to prepare raw chopped beef, chicken tenders, and salmon fillet. As shown in Tables 3 and 4, there were no significant differences (*P* > 0.05) in microbial reductions between NEW and QUAT treatments. Within the first minute of treatment, less than 2 log/100 cm² of microbial reductions were achieved in both board surface materials, however, the antimicrobial effectiveness was more intense against microbial loads on polypropylene compared to wooden surfaces. After 3 min of treatment, microbial loads were further reduced to less than 1 log and were not detected due to lethal injury after 5 min of treatment in both surface materials. Lactic acid treatment was less effective with limited efficacy, about 0.5, 1, and < 2 log/100 cm² of microbial reductions were achieved within 1, 3 and 5 min of treatment, respectively, in which effectiveness was higher in polypropylene boards. Obviously, the antimicrobial effectiveness of the three treatments in both cutting board types was significantly restricted when solutions applied on surfaces used to prepare raw meat compared to bacterial inoculated surfaces. In a study used inoculated food intermediate to contaminate scarred hardwood cutting boards, it was found that manual washing and rinsing followed by sanitization with NEW and NaClO (~100 mg/L) produced similar levels of bacterial inactivation in which the population reductions were less than 5 log CFU/100 cm² (3.4 and 3.6 log for *E. coli*, and 4.1 and 3.9 log for *L. innocua*, respectively) (Monnin and others 2012). Organic matter may inactivate and
reduce the effectiveness of chemical sanitizers; accordingly, to achieve the 5-log reduction (99.999%) in microbial loads, chemical sanitizers must be applied to surfaces that are free of organic matter (Gaulin and others 2011; Pfuntner and others 2011). It was reported that organic matter from food residues (grease and proteins) may harbor bacteria and prevent sanitizers to be in direct physical contact with surfaces to be sanitized (Fraser and Pascall, 2010).

**Conclusions**

This study revealed that NEW could be used as an effective antimicrobial treatment alternative to commonly used chemical sanitizers such as QUATS. NEW also showed a broad spectrum of action against the evaluated bacterial strains inoculated onto both types of surface materials. However, the obtained results demonstrated that the examined treatments were more effective against microbial contamination on polypropylene compared to wooden surfaces. It was found that using of lactic acid as a sanitizer may not be a suitable option to decontaminate food cutting boards. A considerable decline in antimicrobial effectiveness was observed when both cutting board types had been used to prepared raw meat, which could be due to the presence of food organic residues.

**Acknowledgments**

This research was supported by Agricultural Research Center at Washington State University, the University of Jordan and USDA-NIFA 2011-68003-20096. We would like to express our sincere thanks to Mr. Mark Nagano at Greenspeed for providing the industrial neutral electrolyzed water.

**References**


<table>
<thead>
<tr>
<th>Treatment solution-Time (min)</th>
<th>S. Typhimurium</th>
<th>E. coli O157:H7</th>
<th>C. jejuni</th>
<th>L. monocytogenes</th>
<th>S. aureus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NEW</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>8.15 ± 0.07(^a)</td>
<td>8.20 ± 0.07(^a)</td>
<td>7.50 ± 0.06(^a)</td>
<td>8.23 ± 0.07(^a)</td>
<td>8.30 ± 0.05(^a)</td>
</tr>
<tr>
<td>1</td>
<td>4.43 ± 0.05(^c) (3.72)</td>
<td>4.68 ± 0.04(^d) (3.52)</td>
<td>4.23 ± 0.04(^d) (3.27)</td>
<td>4.38 ± 0.04(^e) (3.85)</td>
<td>4.55 ± 0.05(^d) (3.75)</td>
</tr>
<tr>
<td>3</td>
<td>3.65 ± 0.05(^g) (4.50)</td>
<td>3.95 ± 0.04(^e) (4.25)</td>
<td>3.18 ± 0.07(^f) (4.32)</td>
<td>3.35 ± 0.05(^f) (4.88)</td>
<td>3.43 ± 0.05(^e) (4.87)</td>
</tr>
<tr>
<td>5</td>
<td>2.83 ± 0.04(^i) (5.32)</td>
<td>3.01 ± 0.04(^f) (5.19)</td>
<td>2.35 ± 0.04(^g) (5.15)</td>
<td>2.58 ± 0.04(^g) (5.65)</td>
<td>2.75 ± 0.05(^f) (5.55)</td>
</tr>
<tr>
<td><strong>QUAT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>8.10 ± 0.06(^a)</td>
<td>8.13 ± 0.07(^a)</td>
<td>7.43 ± 0.06(^a)</td>
<td>8.33 ± 0.07(^a)</td>
<td>8.15 ± 0.05(^a)</td>
</tr>
<tr>
<td>1</td>
<td>4.73 ± 0.06(^d) (3.37)</td>
<td>4.73 ± 0.05(^d) (3.40)</td>
<td>4.33 ± 0.04(^d) (3.10)</td>
<td>4.70 ± 0.04(^d) (3.63)</td>
<td>4.38 ± 0.05(^d) (3.77)</td>
</tr>
<tr>
<td>3</td>
<td>3.95 ± 0.05(^f) (4.15)</td>
<td>4.00 ± 0.04(^e) (4.13)</td>
<td>3.40 ± 0.05(^e) (4.03)</td>
<td>3.50 ± 0.05(^f) (4.83)</td>
<td>3.45 ± 0.05(^e) (4.70)</td>
</tr>
<tr>
<td>5</td>
<td>3.05 ± 0.04(^b) (5.05)</td>
<td>3.02 ± 0.05(^f) (5.11)</td>
<td>2.41 ± 0.04(^g) (5.02)</td>
<td>2.73 ± 0.04(^g) (5.60)</td>
<td>2.78 ± 0.05(^f) (5.37)</td>
</tr>
<tr>
<td><strong>Lactic acid</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>8.05 ± 0.07(^a)</td>
<td>8.25 ± 0.07(^a)</td>
<td>7.38 ± 0.06(^a)</td>
<td>8.20 ± 0.07(^a)</td>
<td>8.25 ± 0.05(^a)</td>
</tr>
<tr>
<td>1</td>
<td>6.58 ± 0.06(^b) (1.47)</td>
<td>6.65 ± 0.05(^b) (1.60)</td>
<td>5.85 ± 0.04(^b) (1.53)</td>
<td>6.33 ± 0.04(^b) (1.87)</td>
<td>6.34 ± 0.04(^b) (1.91)</td>
</tr>
<tr>
<td>3</td>
<td>5.95 ± 0.05(^c) (2.10)</td>
<td>6.20 ± 0.04(^c) (2.05)</td>
<td>5.35 ± 0.05(^c) (2.03)</td>
<td>5.63 ± 0.05(^c) (2.57)</td>
<td>5.80 ± 0.05(^c) (2.45)</td>
</tr>
<tr>
<td>5</td>
<td>5.76 ± 0.04(^c) (2.29)</td>
<td>6.02 ± 0.04(^c) (2.23)</td>
<td>5.18 ± 0.04(^c) (2.20)</td>
<td>5.45 ± 0.04(^c) (2.75)</td>
<td>5.63 ± 0.04(^c) (2.62)</td>
</tr>
</tbody>
</table>

1 Values are the means of three independent replicate trials ± standard error, with log\(_{10}\) reductions (CFU/100 cm\(^2\)) presented in parentheses.

2 Within the same column, treatment means without shared superscripts are significantly different (Tukey's HSD test, \(P<0.05\)).
Table 2-Mean viable bacterial counts (log$_{10}$ CFU/100 cm$^2$) recovered on wooden cutting boards surfaces after treatment with NEW, QUAT and lactic acid based antimicrobial solutions$^{1,2}$.

<table>
<thead>
<tr>
<th>Treatment solution- Time (min)</th>
<th>S. Typhimurium</th>
<th>E. coli O157:H7</th>
<th>C. jejuni</th>
<th>L. monocytogenes</th>
<th>S. aureus</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>$7.90 \pm 0.07^a$</td>
<td>$7.98 \pm 0.07^a$</td>
<td>$7.10 \pm 0.05^a$</td>
<td>$8.00 \pm 0.07^a$</td>
<td>$7.98 \pm 0.05^a$</td>
</tr>
<tr>
<td>1</td>
<td>$5.15 \pm 0.06^d$</td>
<td>$5.30 \pm 0.05^d$</td>
<td>$4.30 \pm 0.04^d$</td>
<td>$5.05 \pm 0.05^d$</td>
<td>$5.17 \pm 0.05^d$</td>
</tr>
<tr>
<td></td>
<td>(2.75)</td>
<td>(2.68)</td>
<td>(2.80)</td>
<td>(2.95)</td>
<td>(2.81)</td>
</tr>
<tr>
<td>3</td>
<td>$4.05 \pm 0.05^e$</td>
<td>$4.10 \pm 0.04^e$</td>
<td>$3.21 \pm 0.05^e$</td>
<td>$3.90 \pm 0.05^e$</td>
<td>$3.82 \pm 0.05^f$</td>
</tr>
<tr>
<td></td>
<td>(3.85)</td>
<td>(3.88)</td>
<td>(3.89)</td>
<td>(4.10)</td>
<td>(4.16)</td>
</tr>
<tr>
<td>5</td>
<td>$3.10 \pm 0.04^f$</td>
<td>$3.13 \pm 0.04^f$</td>
<td>$2.34 \pm 0.04^f$</td>
<td>$2.85 \pm 0.04^f$</td>
<td>$2.87 \pm 0.05^g$</td>
</tr>
<tr>
<td></td>
<td>(4.80)</td>
<td>(4.85)</td>
<td>(4.76)</td>
<td>(5.15)</td>
<td>(5.11)</td>
</tr>
<tr>
<td>QUAT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>$7.87 \pm 0.07^a$</td>
<td>$7.95 \pm 0.07^a$</td>
<td>$7.00 \pm 0.06^a$</td>
<td>$7.98 \pm 0.07^a$</td>
<td>$8.05 \pm 0.06^a$</td>
</tr>
<tr>
<td>1</td>
<td>$5.18 \pm 0.06^d$</td>
<td>$5.15 \pm 0.05^d$</td>
<td>$4.23 \pm 0.04^d$</td>
<td>$5.11 \pm 0.04^d$</td>
<td>$4.94 \pm 0.05^e$</td>
</tr>
<tr>
<td></td>
<td>(2.69)</td>
<td>(2.80)</td>
<td>(2.77)</td>
<td>(2.87)</td>
<td>(3.11)</td>
</tr>
<tr>
<td>3</td>
<td>$4.10 \pm 0.05^e$</td>
<td>$4.08 \pm 0.04^e$</td>
<td>$3.28 \pm 0.05^e$</td>
<td>$3.95 \pm 0.05^e$</td>
<td>$3.78 \pm 0.04^f$</td>
</tr>
<tr>
<td></td>
<td>(3.77)</td>
<td>(3.87)</td>
<td>(3.72)</td>
<td>(4.03)</td>
<td>(4.27)</td>
</tr>
<tr>
<td>5</td>
<td>$3.25 \pm 0.04^f$</td>
<td>$3.25 \pm 0.04^f$</td>
<td>$2.42 \pm 0.04^f$</td>
<td>$2.93 \pm 0.04^f$</td>
<td>$2.90 \pm 0.05^g$</td>
</tr>
<tr>
<td></td>
<td>(4.62)</td>
<td>(4.70)</td>
<td>(4.58)</td>
<td>(5.05)</td>
<td>(5.15)</td>
</tr>
<tr>
<td>Lactic acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>$7.85 \pm 0.07^a$</td>
<td>$7.90 \pm 0.07^a$</td>
<td>$7.03 \pm 0.06^a$</td>
<td>$7.90 \pm 0.06^a$</td>
<td>$7.93 \pm 0.07^a$</td>
</tr>
<tr>
<td>1</td>
<td>$6.65 \pm 0.06^b$</td>
<td>$6.65 \pm 0.05^b$</td>
<td>$5.73 \pm 0.04^b$</td>
<td>$6.33 \pm 0.04^b$</td>
<td>$6.28 \pm 0.05^b$</td>
</tr>
<tr>
<td></td>
<td>(1.20)</td>
<td>(1.25)</td>
<td>(1.30)</td>
<td>(1.57)</td>
<td>(1.65)</td>
</tr>
<tr>
<td>3</td>
<td>$6.03 \pm 0.05^c$</td>
<td>$6.15 \pm 0.04^c$</td>
<td>$5.25 \pm 0.05^c$</td>
<td>$5.70 \pm 0.05^c$</td>
<td>$5.65 \pm 0.06^c$</td>
</tr>
<tr>
<td></td>
<td>(1.82)</td>
<td>(1.75)</td>
<td>(1.78)</td>
<td>(2.20)</td>
<td>(2.28)</td>
</tr>
<tr>
<td>5</td>
<td>$5.85 \pm 0.04^c$</td>
<td>$5.99 \pm 0.04^c$</td>
<td>$5.07 \pm 0.04^c$</td>
<td>$5.52 \pm 0.04^c$</td>
<td>$5.48 \pm 0.04^c$</td>
</tr>
<tr>
<td></td>
<td>(2.00)</td>
<td>(1.91)</td>
<td>(1.96)</td>
<td>(2.38)</td>
<td>(2.45)</td>
</tr>
</tbody>
</table>

$^1$ Values are the means of three independent replicate trials ± standard error, with log$_{10}$ reductions (CFU/100 cm$^2$) presented in parentheses.

$^2$ Within the same column, treatment means without shared superscripts are significantly different (Tukey's HSD test, $P<0.05$).
Table 3-Mean viable counts (log$_{10}$ CFU/100 cm$^2$) recovered on polypropylene cutting boards surfaces used to prepare meat samples after treatment with NEW, QUAT and lactic acid based antimicrobial solutions$^{1,2,3}$.

<table>
<thead>
<tr>
<th>Treatment solution</th>
<th>Meat sample</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chopped beef</td>
<td>Chicken tenders</td>
<td>Salmon fillet</td>
</tr>
<tr>
<td>NEW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>3.10 ± 0.05$^a$</td>
<td>3.28 ± 0.05$^a$</td>
<td>3.80 ± 0.05$^a$</td>
</tr>
<tr>
<td>1</td>
<td>1.43 ± 0.04$^d$</td>
<td>1.67 ± 0.05$^d$</td>
<td>2.05 ± 0.04$^d$</td>
</tr>
<tr>
<td>(1.67)</td>
<td>(1.61)</td>
<td>(1.75)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&lt;1$^e$</td>
<td>&lt;1$^e$</td>
<td>&lt;1$^e$</td>
</tr>
<tr>
<td>5</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>QUAT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>2.97 ± 0.05$^a$</td>
<td>3.15 ± 0.05$^a$</td>
<td>3.70 ± 0.05$^a$</td>
</tr>
<tr>
<td>1</td>
<td>1.37 ± 0.04$^d$</td>
<td>1.62 ± 0.05$^d$</td>
<td>2.00 ± 0.04$^d$</td>
</tr>
<tr>
<td>(1.60)</td>
<td>(1.53)</td>
<td>(1.70)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&lt;1$^e$</td>
<td>&lt;1$^e$</td>
<td>&lt;1$^e$</td>
</tr>
<tr>
<td>5</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>Lactic acid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>3.01 ± 0.05$^a$</td>
<td>3.20 ± 0.05$^a$</td>
<td>3.65 ± 0.05$^a$</td>
</tr>
<tr>
<td>1</td>
<td>2.34 ± 0.04$^b$</td>
<td>2.60 ± 0.06$^b$</td>
<td>3.03 ± 0.04$^b$</td>
</tr>
<tr>
<td>(0.67)</td>
<td>(0.60)</td>
<td>(0.62)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.81 ± 0.04$^c$</td>
<td>2.10 ± 0.05$^c$</td>
<td>2.56 ± 0.03$^c$</td>
</tr>
<tr>
<td>(1.20)</td>
<td>(1.10)</td>
<td>(1.09)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.28 ± 0.03$^d$</td>
<td>1.50 ± 0.03$^d$</td>
<td>1.93 ± 0.03$^d$</td>
</tr>
<tr>
<td>(1.73)</td>
<td>(1.70)</td>
<td>(1.72)</td>
<td></td>
</tr>
</tbody>
</table>

$^1$ Values are the means of three independent replicate trials ± standard error, with log$_{10}$ reductions (CFU/100 cm$^2$) presented in parentheses.

$^2$ Within the same column, treatment means without shared superscripts are significantly different (Tukey’s HSD test, $P<0.05$).

$^3$ ND, not detected due to lethal injury.
Table 4-Mean viable counts (log_{10} CFU/100 cm²) recovered on wooden cutting boards surfaces used to prepare meat samples after treatment with NEW, QUAT and lactic acid based antimicrobial solutions¹, ², ³.

<table>
<thead>
<tr>
<th>Treatment solution</th>
<th>Time (min)</th>
<th>Meat sample</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Chopped beef</td>
<td>Chicken tenders</td>
<td>Salmon fillet</td>
<td></td>
</tr>
<tr>
<td><strong>NEW</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>3.17 ± 0.05ᵃ</td>
<td>3.45 ± 0.05ᵃ</td>
<td>3.87 ± 0.05ᵃ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.75 ± 0.05ᵈ</td>
<td>2.19 ± 0.05ᵈ</td>
<td>2.46 ± 0.04ᵈ</td>
<td>(1.42)</td>
<td>(1.26)</td>
</tr>
<tr>
<td>3</td>
<td>&lt;1ᵉ</td>
<td>&lt;1ᵉ</td>
<td>&lt;1ᵉ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>QUAT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>3.21 ± 0.05ᵃ</td>
<td>3.40 ± 0.05ᵃ</td>
<td>3.78 ± 0.05ᵃ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.83 ± 0.04ᵈ</td>
<td>2.23 ± 0.04ᵈ</td>
<td>2.33 ± 0.04ᵈ</td>
<td>(1.38)</td>
<td>(1.17)</td>
</tr>
<tr>
<td>3</td>
<td>&lt;1ᵉ</td>
<td>&lt;1ᵉ</td>
<td>&lt;1ᵉ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lactic acid</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>3.15 ± 0.05ᵃ</td>
<td>3.35 ± 0.05ᵃ</td>
<td>3.75 ± 0.05ᵃ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2.65 ± 0.04ᵇ</td>
<td>2.87 ± 0.06ᵇ</td>
<td>3.18 ± 0.04ᵇ</td>
<td>(0.50)</td>
<td>(0.48)</td>
</tr>
<tr>
<td>3</td>
<td>2.15 ± 0.04ᶜ</td>
<td>2.50 ± 0.05ᶜ</td>
<td>2.83 ± 0.03ᶜ</td>
<td>(1.00)</td>
<td>(0.85)</td>
</tr>
<tr>
<td>5</td>
<td>1.65 ± 0.03ᵈ</td>
<td>2.05 ± 0.03ᵈ</td>
<td>2.28 ± 0.03ᵈ</td>
<td>(1.50)</td>
<td>(1.30)</td>
</tr>
</tbody>
</table>

¹ Values are the means of three independent replicate trials ± standard error, with log_{10} reductions (CFU/100 cm²) presented in parentheses.
² Within the same column, treatment means without shared superscripts are significantly different (Tukey's HSD test, P<0.05).
³ ND, not detected due to lethal injury.