Chemical Decontamination of Campylobacter jejuni on Chicken Skin and Meat

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ABSTRACT

This study evaluated the effectiveness of 11 chemical compounds to reduce Campylobacter jejuni on chicken skin and meat samples dipped in chemical solutions. Treatment of skin samples for 1 min using tartaric acid (2%) and caprylic acid sodium salt (5%) caused reductions of C. jejuni NCTC11168, which were not significantly different from the reduction obtained by sterile water (0.95 log). Statistically larger reductions (1.57 to 3.81 log) were caused by formic acid (2%), lactic acid (2.5%), trisodium phosphate (10%), capric acid sodium salt (5%), grapefruit seed extract (1.6%), and chlorhexidine diacetate salt hydrate (1%). The most effective compounds were cetylpyridinium chloride (0.5%) and benzalkonium chloride (1%) (>4.2 log). However, when these treated samples were stored for 24 h at 5°C, cetylpyridinium chloride, benzalkonium chloride, and grapefruit seed extract were less effective, indicating that some cells may recover after a 1-min treatment with these chemicals. An increase in treatment time to 15 min resulted in higher effectiveness of trisodium phosphate and formic acid. Interestingly, when reduction of the C. jejuni population was compared on chicken skin and meat, sterile water and lactic acid caused considerably larger reductions on skin than on meat, whereas the opposite was seen for caprylic acid sodium salt. In conclusion, this study has identified chemicals with substantial reduction effects on C. jejuni. The analysis has further emphasized that treatment time and food matrix affect the outcome in an unpredictable manner and, therefore, detailed studies are needed to evaluate the reduction effectiveness of chemicals.

Campylobacteriosis is the most commonly identified bacterial foodborne infection in humans in developed countries. The infection is primarily characterized by gastrointestinal disease, but in rare cases, it may cause life-threatening sequelae such as Guillain-Barré syndrome, with paralysis of muscles due to injury of the peripheral nervous system (23, 50). Campylobacter is often carried in high numbers in the intestinal tract of symptom-free mammals and birds (23, 38), and fecal contamination of fresh chicken meat during processing is considered a major source of human Campylobacter infections (23, 24, 38, 39, 49). While consumers are at risk of infection through undercooked chicken, the handling of raw chicken in the kitchen and cross-contamination to prepared foods is believed to present an even greater risk (28, 29).

Surveillance of Campylobacter in Denmark has shown that hygienic measures during domestic production of fresh chicken meat, such as improved biosecurity at the farm level, logistic slaughter in the processing plant, and information at the consumer level, have so far proved inadequate in significantly reducing the number of human cases of campylobacteriosis (1, 2). Consequently, there is an urgent need for alternative intervention strategies. Numerous risk assessments on Campylobacter in broilers have been carried out worldwide, and several of these assessments suggest that interventions aimed at reducing the number of Campylobacter on carcasses during processing will subsequently lead to a decline in the incidence of human campylobacteriosis (25, 37). One possible intervention strategy could be the application of chemical decontamination of carcasses. While chemical decontamination is already implemented in some U.S poultry slaughtering plants (35), the European Union only just recently provided the legal basis for the use of substances other than potable water to remove microbial surface contamination from products of animal origin (18). However, no products for chemical decontamination have yet been authorized by the European Union as the European Food Safety Authority’s guidelines regarding documentation on safety and efficacy of the chemicals have so far not been met in any of the evaluated applications (19–22).

Implementation of chemical decontamination against Campylobacter on chicken carcasses in the processing plant requires considerations regarding the chemistry, and most importantly, the reduction capacity. However, additional criteria, such as consumer acceptance, human health aspects, development of antimicrobial resistance, environmental safety, cost, and microflora changes, have to be considered as well (22, 40). Disadvantages have been described for the use of certain commercial decontamination compounds, for instance, sensitivity to organic material, discoloration of chicken skin, or pollution of the environment (7, 34, 40). The commercial alkaline salt trisodium phosphate (TSP) in solutions of 8 to 12% has a well-described

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TABLE 1. Chemicals used in this study

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Active compound</th>
<th>Manufacturer</th>
<th>% concn (wt/vol)</th>
<th>Solution pH*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sterile water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tartaric acid (TA)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Organic acid</td>
<td>Riedel-deHäën, L+ puriss</td>
<td>2</td>
<td>2.58 ± 0.04 (3)</td>
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<tr>
<td>Lactic acid (LA)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Organic acid</td>
<td>Bie &amp; Berntsen, LD 80%</td>
<td>2.5</td>
<td>3.07 ± 0.08 (5)</td>
</tr>
<tr>
<td>Formic acid (FA)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Organic acid</td>
<td>Fluka</td>
<td>2</td>
<td>2.86 ± 0.07 (5)</td>
</tr>
<tr>
<td>Trisodium phosphate (TSP)&lt;sup&gt;e&lt;/sup&gt;</td>
<td>Salt of phosphoric acid</td>
<td>Riedel-deHäën, min 94%</td>
<td>10</td>
<td>12.02 ± 0.08 (5)</td>
</tr>
<tr>
<td>Caprylic acid sodium salt (CY)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Fatty acid salt</td>
<td>Sigma</td>
<td>5</td>
<td>—</td>
</tr>
<tr>
<td>Caprylic acid sodium salt (CA)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Fatty acid salt</td>
<td>Sigma</td>
<td>5</td>
<td>—</td>
</tr>
<tr>
<td>Grapefruit seed extract (GSE)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Plant extract</td>
<td>Elephanta</td>
<td>1.6</td>
<td>3.92 ± 0.23 (3)</td>
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<td>Chlorhexidine diacetate salt hydrate (CHX)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Bis-bis-guanide</td>
<td>Sigma</td>
<td>1</td>
<td>8.58 ± 0.17 (5)</td>
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<tr>
<td>Cetylpyridinium chloride (CPC)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>QAC&lt;sup&gt;e&lt;/sup&gt;</td>
<td>Sigma</td>
<td>0.5</td>
<td>5.99 ± 0.05 (3)</td>
</tr>
<tr>
<td>Benzalkonium chloride (BZ)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>QAC&lt;sup&gt;e&lt;/sup&gt;</td>
<td>Sigma</td>
<td>1</td>
<td>4.94 ± 0.10 (5)</td>
</tr>
</tbody>
</table>

*Mean ± standard deviation of pH measurements performed in a number of solutions (n presented in parentheses).

<sup>a</sup> Not previously tested for the ability to reduce *Campylobacter*.

<sup>b</sup> Commercial decontamination product in poultry processing plants.

<sup>c</sup> Formic acid (pH 4.0), caprylic acid (10 mM), caprylic acid (10 mM), and benzalkonium chloride (1%) have previously been shown to reduce *Campylobacter* significantly in vitro (4, 15, 27).

<sup>d</sup> QAC, quaternary ammonium compound.

The effect of several chemical compounds against *C. jejuni* in a chicken skin model setup that is comparable to a chemical dipping procedure during chicken processing. As indicated in Table 1, we chose to test commercial decontamination products (TSP, CPC, and lactic acid [LA]) or compounds, which are classified to the same chemical group as the commercial products (tartaric acid [TA], formic acid [FA], and benzalkonium chloride [BZ]). Chemicals with reduction effect against *C. jejuni* in vitro (caprylic acid [CA] and caprylic acid [CY] sodium salts) were also included as well as compounds with reduction effectiveness against *Salmonella* in food products (grapefruit seed extract [GSE] and chlorohexidine diacetate [CHX]) (26, 46, 51). Because meat surfaces of the chicken carcass may also be contaminated with *C. jejuni* during processing, we tested the decontamination effect of selected chemicals in a chicken meat model. This allowed us to compare survival of *C. jejuni* on chicken skin and meat during chemical treatment under standardized experimental conditions.

### MATERIALS AND METHODS

#### Bacterial strain and growth conditions.

The clinical human isolate *C. jejuni* NCTC11168 used in the study was obtained from the National Collection of Type Cultures. This strain was maintained in brain heart infusion broth (Oxoid, Ltd., Basingstoke, UK) containing 15% glycerol at −80°C. It was routinely grown at 37°C on blood agar base no. 2 (Oxoid, Ltd.) supplemented with 5% calf blood (Base II) in sealed gas jars in a microaerobic environment (80% N₂, 7% H₂, 7% CO₂, and 6% O₂) provided by an ANOXOMAT (MART, Microbiology B.V., Drachten, The Netherlands).

#### Chemical solutions.

Chemical solutions were prepared in sterile water immediately before each experiment. Shown in Table 1 are solution, manufacturer, and pH for each chemical discussed in the following sections. In addition, Table 1 includes comments regarding reduction of *C. jejuni* from previous studies in which the chemicals were tested.

#### Preparation of inoculum.

A small amount of frozen stock culture of *C. jejuni* was plated on Base II, grown for 72 h, then restreaked on Base II plates, and finally incubated at 37°C for 24 h. Bacteria were harvested with phosphate-buffered saline (PBS, pH 7.3; Oxoid Ltd.), and the optical density at 600 nm was measured (Helios Epsilon, Thermo Spectronic, Rochester, NY). From previous experiments it was known that optical density at 600 nm of 0.1 in PBS corresponds to approximately 10⁸ CFU/ml. Based on this knowledge, the volume of *C. jejuni* culture in PBS to be suspended in 5 ml of sterilized chicken juice was calculated in order to achieve a final concentration of approximately 4 × 10⁸ CFU/ml in the chicken juice. The chicken juice was derived from frozen retail chickens without giblets, which were thawed overnight at room temperature in a plastic container. The meat juices from 10 chickens were mixed, larger particles were removed by centrifugation at 10,000 rpm (centrifuge 5810R, Eppendorf, Hamburg, Germany) for 10 min, the supernatant was sterilized through...
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Preparation of chicken skin and meat samples. Frozen Campylobacter-negative chickens without giblets (DANPO, Denmark, The Netherlands) were thawed overnight in plastic bags at 5°C. Samples of chicken skin and meat were aseptically cut out of the chicken carcass by using a stainless steel coring tool with a 35-mm-diameter opening. Skin samples were cut from the dorsal part of the carcass, and each sample was placed, covering the 15-mm-diameter opening of a plastic centrifuge tube, with the upper epithelium layer of the skin positioned outward. The skin was secured to the tube with a rubber band, forming a slightly concave surface that was covered with aluminum foil. The meat from breast fillets covered with fascia was cut into samples of 0.5-cm thickness and placed on a piece of gauze pad inside a petri dish. Samples of meat and skin were stored at room temperature (25 ± 2°C) until use (maximum 2 h) while kept inside a plastic bag with a wet towel to prevent desiccation.

Inoculation of skin and meat samples. Skin samples were each inoculated with a 50-μl droplet of C. jejuni in sterilized chicken juice on the concave surface of skin. With respect to the meat fascia surface, 50 μl of C. jejuni sterilized chicken juice was added within seconds by letting the pipette gently touch the meat surface and leave a few microliters of inoculum at a time. The C. jejuni cells were allowed to adhere to the skin and meat samples for 20 min at room temperature before samples were either used to determine the inoculation level or chemically treated.

Chemical treatment of chicken skin and meat samples. Chemical solutions of 40 ml were kept in glass bottles at room temperature, and separate solutions were for treatment of each skin or meat sample. Skin samples were dipped while secured to the opening of a centrifuge tube that floated upside down in the solution, while meat samples were held by surgical tweezers. These dipping treatments were conducted for 15 s, 1 min, 5 min, or 15 min, and this was immediately followed by quantification of C. jejuni in the samples. In addition, other samples were dipped for 1 min in chemical solution and subsequently stored for 24 h at 5°C before quantification. During storage, the samples were placed on gauze in Petri dishes that were contained inside moist plastic bags.

Quantification of C. jejuni in skin and meat rinse. Skin or meat samples were homogenized by stomaching for 2 min in 100 ml of buffered peptone water (dilution of 10³) (Oxoid, Ltd.). The gauze was stomached together with those meat or skin samples that had been stored for 24 h at 5°C. The large rinse volume was applied to dilute quickly any chemical solution left on the surfaces of the skin or meat samples. From skin and meat rinses (dilution of 10³), 10-fold serial dilutions were produced in buffered peptone water, and 10 μl of appropriate dilutions was spotted in triplicate on dried modified Abeyta-Hunt-Bark agar plates supplemented with triphenyl-tetrazolium chloride (38). The plates were incubated under microaerobic conditions at 42°C for 48 h, and CFU per milliliter was determined. Using this method, the detection limit for C. jejuni was 1.18 CFU/ml. In every experiment, the initial inoculation level of C. jejuni in skin or meat rinses was determined before any chemical treatment was applied by calculating the mean CFU per milliliter in rinses from two samples to which C. jejuni had adhered for 20 min. For all of the experiments, the average initial level in skin rinse was 5.37 log CFU/ml (±0.25 standard deviation) and in meat rinse was 5.56 log CFU/ml (±0.23 standard deviation). For a single chemically treated sample, reduction in the C. jejuni population was estimated as the difference in CFU per milliliter between the initial level in the experiment and the level in the treated sample. Subsequently, from all experiments, an estimation of the reduction mean and standard error of the mean (SEM) for each chemical treatment was performed. As can be seen in Table 2 and Figures 1 and 2, the number of experiments varied from 3 to 18 for each chemical treatment. Additionally, the chemical treatment was carried out on duplicate samples in each experiment.

Measurement of pH of chemical solutions and skin and meat surfaces. The pH was measured by using a pH meter (PHM-92, Radiometer, Copenhagen, Denmark) at 25 ± 2°C. Measurement of pH in chemical solutions was carried out before use of the solutions (Electrode pHC, Radiometer), and the mean and standard deviation of pH calculated from 3 to 5 replicate measurements. A pH-sensitive electrode for measurement of the pH of C. jejuni in chicken skin rinses was measured with two additional samples to which C. jejuni had adhered for 20 min. For all of the experiments, the average initial level in skin rinse was 5.37 log CFU/ml (±0.25 standard deviation) and in meat rinse was 5.56 log CFU/ml (±0.23 standard deviation). For a single chemically treated sample, reduction in the C. jejuni population was estimated as the difference in CFU per milliliter between the initial level in the experiment and the level in the treated sample. Subsequently, from all experiments, an estimation of the reduction mean and standard error of the mean (SEM) for each chemical treatment was performed. As can be seen in Table 2 and Figures 1 and 2, the number of experiments varied from 3 to 18 for each chemical treatment. Additionally, the chemical treatment was carried out on duplicate samples in each experiment.

Statistical analysis. C. jejuni counts (CFU per milliliter) were log transformed to approximate the data to normal distributions.
RESULTS

Reduction in C. jejuni population caused by chemical treatment of chicken skin. Eleven different chemicals (Table 1) were tested for their decontamination effect against C. jejuni on chicken skin in a 1-min dip procedure (Table 2). Sterile water was included as a control for the effect of the dip procedure alone, which caused a reduction of 0.95 log. Subsequent to chemical treatment, neither the organic acid TA (0.91 log) nor the fatty acid salt CY (1.35 log) showed a reduction significantly different from water. Therefore, at the concentrations tested, these compounds did not appear to reduce C. jejuni on chicken skin. In contrast, all other tested compounds exhibited reductions significantly larger than the reduction obtained by water. The reductions caused by the organic acids FA (1.57 log) and LA (1.69 log), the alkali salt TSP (1.74 log), and the fatty acid salt CA (1.78 log) were all statistically similar. The plant extract GSE exhibited a considerably larger reduction of 3.05 log and the bis-bis-guanidine compound CHX exceeded this effect, causing a 3.81-log reduction. The most effective compounds were the quaternary compounds CPC and BZ, for which no C. jejuni was detected in the skin rinses after treatment (>4.2-log reduction).

In order to provide an indirect measure of whether the 1-min dip procedure had a lasting reduction effect after 24 h of cold storage, we investigated the effect of an extended decontamination procedure in which the 1-min dip treatment was followed by 24 h of storage at 5°C. For most chemicals (water, CHX, TA, LA, FA, TSP, as well as CA and CY), the reductions obtained after 24 h of cold storage were either similar or significantly increased compared with the 1-min dip for the same compounds. This indicates that the 1-min dip procedure utilizing these chemicals caused a lasting reduction of C. jejuni on chicken skin after 24 h of cold storage. The opposite was observed for the GSE plant extract, which showed a significantly lower reduction in C. jejuni population after storage (2.15 log) compared with the reduction determined immediately after the 1-min dip treatment (3.05 log). A decreased reduction after 24 h of cold storage was also observed for the quaternary ammonium compounds CPC and BZ, but in these cases, the reduction was not statistically significant. This indicates that the reduction effect of the 1-min dip with CPC and BZ does not last after 24 h of cool storage.
Effect of chemical treatment time on the reduction of _C. jejuni_ on chicken skin. In order to test the effect of treatment time on reduction of _C. jejuni_ by chemicals, LA, TSP, FA, and water were selected for treatments ranging from 15 s to 15 min (Fig. 1). Dipping in water reduced the _C. jejuni_ population on chicken skin between 0.81 log and 1.04 log, with no significant (P = 0.1381) difference in reduction when the treatment time was increased. In general, there was no significant difference in reduction for these chemicals whether the treatment lasted for 15 s or 1 min. Regarding the organic acid LA, extending the treatment from 1 to 15 min did not result in a statistically significant (P = 0.4850) increase in reduction. In contrast, the alkaline salt TSP caused a significant increase in reduction with a 5-min treatment as compared with the 1-min treatment, while no additional effect was achieved when the treatment time was raised to 15 min. Furthermore, the reduction found for the organic acid FA was significantly larger after 15 min as compared with the other treatment times.

Comparison of chemical treatment against _C. jejuni_ on chicken skin and meat. The decontamination effect of selected chemicals against the _C. jejuni_ population on chicken skin and meat was compared under standardized conditions in bench-top food model systems. For all chemicals tested, except TSP, the food source had a significant influence on the reduction effect of the chemical treatment (Fig. 2). However, there was no common pattern favoring reduction in one type of food source. Water and the organic acid LA caused a significantly larger reduction on chicken skin than on meat after a 1-min dip (Fig. 2A), or 1-min dip that was followed by 24 h storage at 5°C (Fig. 2B). In contrast, the reduction obtained by the fatty acid salt CY was significantly larger on meat than on skin, subsequent to both a 1-min dip (Fig. 2A) and a 1-min dip that was followed by 24 h of storage (Fig. 2B).

**pH on skin and meat surfaces after chemical treatment.** To investigate a possible explanation for the observed differences in reduction of _C. jejuni_ on skin and meat, the pH values on the skin and meat surfaces were measured (Fig. 3). After the 1-min dip, nontreated skin samples had a slightly higher pH than had the nontreated meat samples, but this difference disappeared after 24 h of storage at 5°C. Treatment with water did not change the surface pH. However, after treatment with the acidic and alkaline chemicals, the meat surfaces had pH values that were closer to the nontreated meat compared with the skin surfaces, on which larger pH changes were seen. TSP induced the largest change in pH on skin and meat surfaces, independent of treatment time.

**DISCUSSION**

In recent years, several risk assessments on _Campylobacter_ in broiler chickens have shown that the incidence of human campylobacteriosis could be decreased significantly when the population of _Campylobacter_ is reduced on chicken carcasses during processing (25, 37). In this study, a bench-top model system was used to investigate chemical decontamination of chicken skin and chicken meat inoculated with _C. jejuni_. To avoid any influence of natural _Campylobacter_ contamination, we used carcasses that were guaranteed _Campylobacter_ negative. However, such carcasses could only be obtained frozen, which to some extent may have biased our results, because freezing could change access to feather follicles, where _C. jejuni_ can reside (14).

In our model, we did not include a water wash after chemical treatment, because the aim of this study was to compare the reduction effect of the selected chemicals and not to evaluate a washing procedure. In contrast to other studies of chemical decontamination using chicken model systems, _C. jejuni_ cells were applied to skin or meat suspended in a chicken juice media, which is shown to be superior in supporting survival of _C. jejuni_ under cooling and freezing conditions, as compared with liquid laboratory media (8, 9). Despite the possible limitations in the chicken skin model, data obtained from water and TSP dipping are comparable to results from chemical decontamination washing procedures of full-scale chicken slaughtering plants. In the present study, water reduced _C. jejuni_ approximately 1 log after the 1-min treatment, and this reduction was independent of the increase in treatment time up to 15 min. In a Danish chicken slaughtering plant, carcass water washing and water chilling reduced the load of thermotolerant _Campylobacter_ on neck skin samples by 0.97 log (38) in a process that lasted approximately 22 min. In our study, dipping in 10% TSP for 15 s reduced the _C. jejuni_ population by 1.88 log, which is similar to the reduction of _C. jejuni_ obtained in industrial in-line studies. Dipping chicken carcasses in a 10% TSP solution for 15 s caused a reduction of 1.30 log in a French chicken slaughtering plant (11), and a 1.71-log reduction in an Irish chicken slaughtering plant (48).

Among the chemicals tested in the skin model, the most effective reduction after the 1-min dip was obtained by using 1% CHX, 0.5% CPC, and 1% BZ. These com-

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**FIGURE 3.** The mean pH values on chicken skin and meat surfaces after a 1-min dip in chemicals, or a 1-min dip in chemicals that was followed by storage for 24 h at 5°C. The mean pH values are calculated from a minimum of 3 and a maximum of 11 measurements per treatment. SEM was below 0.1 for the untreated and water-treated samples. SEM was below 0.3 for all other chemical treatments, except the TSP dip of meat for 1 min (SEM = 0.78) and the TSP dip of skin for 1 min, followed by 24 h of cool storage (SEM = 0.62).
pounds are all defined as antiseptics or disinfectants (30). GSE, which is regarded as a natural antimicrobial substance, also exhibited a considerable reduction. However, for this product, it cannot be excluded that it may contain synthetic disinfectants, such as methyl paraben, BZ, benzethonium chloride, and triclosan, because these have been identified as constituents in several GSE extracts (44, 45, 47). Neither CHX nor GSE have been tested previously for their reduction efficacy against thermotolerant Campylobacter, whereas BZ has been tested in a filtration method for susceptibility testing of Campylobacter toward disinfectants, in which it also showed a strong bactericidal effect (4). The reduction effect of 0.5% CPC against C. jejuni in chicken skin bench-top models has been tested prior to this study (3, 31). Meyhar and coworkers (31) dipped chicken drumettes for 1 min in a 0.5% CPC solution, but they observed a reduction of only 0.6 to 0.8 log on the skin. This is in contrast to the complete elimination of C. jejuni on skin after the 1-min dip in CPC found in our study. This apparent discrepancy may be explained by the use of different C. jejuni strains in the experiments, different skin types (wing skin versus dorsal skin), or differences in temperature exposure of skin before treatment (e.g., chilled versus frozen) and differences in support of the skin (nonexcised versus excised skin) (12, 13). In addition, we observed less reduction of C. jejuni on skin after cold storage for 24 h after chemical treatment with CPC, GSE, and BZ, as compared with reduction immediately after chemical treatment. This suggests that C. jejuni cells may recover from sublethal injury caused by some chemical treatments during 24 h of cold storage (16). The potential for recovery of C. jejuni on skin after chemical treatment may actually be supported by the fact that Meyhar and coworkers stored their skin samples for 2 h at 4°C before microbiological analysis, and achieved a much lower reduction with CPC compared to the 1-min dip in our study.

Apart from antiseptics and disinfectants, a series of organic acids were tested in the chicken skin model. LA (2.5%) has been highlighted as a cost-effective intervention strategy in a Dutch risk assessment study (25). However, in our study, it appeared to provide only an additional reduction of 0.7 log compared with water alone (1 log). In addition, the use of LA at a concentration of 2.5% for decontamination of fresh chicken carcasses may be limited because the treatment causes a yellow discoloration of the skin (7). Therefore, we investigated whether a larger reduction could be achieved by application of other organic acids, such as 2% TA or 2% FA. Apparently, this was not the case.

We performed studies with fatty acid salts as decontamination agents, because these may be accepted by consumers, due to their natural occurrence, e.g., CA is a constituent in milk fat (43). We found that the saturated fatty acid salt, 5% CA, caused a considerable (1.78 log) reduction, and the 5% CY caused a minor reduction (1.35 log) in the C. jejuni population on chicken skin. This result, along with an earlier study showing a significant reduction of naturally occurring C. jejuni on poultry skin by the fatty acid salt 4% potassium oleate (27), reveals that fatty acid compounds should be evaluated for their role as future decontamination chemicals.

The focus of this study was on short-time chemical decontamination of C. jejuni during chicken slaughter processing. However, compounds such as LA, TA, TSP, and fatty acid compounds are also allowed as food additives. When evaluating their lasting effect after a 1-min dip that was followed by 24 h of cold storage, we found major reductions. Therefore, in the future, it may be recommended to evaluate their application in marinades at low concentrations for the reduction of C. jejuni on chicken products.

A short decontamination treatment time, e.g., less than 1 min, is most feasible with regard to integration of decontamination as an in-line operation during processing. In the present study, treatment times up to 15 min were also evaluated in the chicken skin model, because longer treatment times may be relevant with new application strategies in the processing plant in the future (6). The 10% TSP and 2.5% LA solutions were chosen as representatives of commercial decontamination compounds, while the organic acid 2% FA was as an alternative to LA. Water showed a fixed reduction of approximately 1 log, independent of treatment time (15 s to 15 min) (Fig. 1), which implies that increased passive immersion time of carcasses is probably not a feasible intervention strategy. Regarding 10% TSP, treatment times of 5 min and 15 min caused an additional reduction of approximately 1 log as compared with dipping for 1 min or 15 s. TSP solutions at concentrations of 8 to 12% are applied by dipping or spraying carcasses for up to 15 s in some U.S. poultry processing plants (41), but increasing the treatment time of TSP may be advantageous. LA in a 2.5% solution, exhibited a slight-but-insignificant increase in reduction when the treatment time was raised to 5 min or more, as compared with treatments less than 5 min. In contrast, 2% FA caused a dramatic increase in reduction when the treatment time was raised from 5 to 15 min. Therefore, our data show that even within the same chemical group, it is difficult to predict the reduction effect if the treatment time is extended.

C. jejuni is considered primarily found on the surface of chicken carcasses and the skin is the surface mainly exposed during chemical decontamination in a processing plant. However, during processing, meat surfaces are also likely to become contaminated, e.g., in the carcass cavity or neck area. Even a few Campylobacter cells on the meat surface pose a risk to humans (10); therefore, it is essential to investigate if the meat surface is properly decontaminated as well. Our results showed that the decontamination effect of water, 2.5% LA, 5% CY, and 5% CA was significantly different when chicken skin or chicken meat was treated. In contrast, the reduction observed for 10% TSP seemed independent of surface type. Our data suggest that it is not possible to make general predictions about which food surface favors the largest reduction during chemical decontamination. In support of this notion, it has been shown previously that the survival of C. jejuni is strongly dependent on the type of laboratory media used and the food surface during acid stress, cold storage, and freezing.
Presumably, no single factor can explain the observed difference in reduction of C. jejuni on skin and meat. However, physical and/or chemical parameters, such as buffer capacity or microtopography of the food surface, may contribute. If the large buffer capacity of chicken breast meat (36) is the main explanation for the observed differences, one would expect a lower reduction on meat than on skin when treated with the acidic and alkaline solutions. It may be argued that the buffer capacity can explain the reduction observed by LA in our study. After LA treatment, the pH values of the meat were higher (approximately 4.0 and 6.0) than those for the skin (approximately 3.5 and 4.5) and as a result, the reduction was lower on meat than on skin. Nevertheless, for none of the other chemicals tested did the reduction pattern favor a specific food surface, even though the buffer capacity was higher on meat than on skin.

In conclusion, our chicken model–based analysis identified chemicals with a considerable reduction effect against C. jejuni. The analysis further emphasized the unpredictable nature of the chemicals, with respect to treatment time and the food matrix, and shows that detailed studies are needed to evaluate the reduction effect of chemicals. In addition, effects in large-scale production, as well as toxicological, human health, environmental, and food sensory quality aspects must be investigated for the noncommercial products.

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