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Abstract

Traditional meat preservation techniques such as smoking, drying, and salting have various shortcomings and limitations in effectively reducing microbial loads and maintaining meat quality. Consequently, chemical compounds have gained attention as promising alternatives for decontamination, offering the potential to extend shelf life and minimize physical, chemical, and sensory changes in meat. Chlorine-based compounds, trisodium phosphate, organic acids, bacteriocins, lactoferrin, and peracetic acid are technologies of recent industrial applications that inhibit spoilage and pathogenic microorganisms in meat. This review explores the critical aspects of decontamination and assesses the efficacy of different chemical compounds employed in meat preservation. These compounds exhibit strong microorganism inactivation capabilities, ensuring minimal alterations to the meat matrix and substantially reducing environmental impact.

Keywords : Decontamination, Meat, Chemical technology

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Introduction

Consumers expect safe and high-quality meat when making purchases and during consumption. However, meat is highly susceptible to contamination and spoilage due to microorganisms and pathogens, which pose significant health risks to consumers. Traditional preservation techniques, such as refrigeration and freezing, often do not eliminate microbial threats (Sofos and Geornaras, 2010). Thus, it is crucial to implement effective and reliable preservation methods to maintain the safety and hygiene of meat products (Mallhi et al., 2022).

Chemical decontamination strategies play a critical role in enhancing the safety and shelf-life of meat by reducing or eliminating pathogenic microorganisms. These methods are essential in meat processing environments, where contamination by pathogenic bacteria can occur during slaughter and processing. Various chemical agents, including organic acids (lactic acid, acetic acid), chlorine compounds, and peroxyacetic acid, have been widely studied (Gill and Badoni, 2004; Rutala and Weber, 2013; Taylor and Stephanie, 2020) and employed in reducing microbial loads on meat surfaces. Early research focused on reducing overall bacterial counts, but recent approaches have shifted toward pathogen control within a Hazard Analysis and Critical Control Point (HACCP) system (Motarjemi and Warren, 2023). Chemical compounds function by breaking down microbial cell membranes, interfering with their metabolic processes, or inducing oxidative damage, ultimately resulting in the inactivation of pathogens (Pérez-Rodríguez and Mercanoglu, 2019). However, their application must be strictly controlled to prevent any negative impact on the sensory properties of meat and to ensure adherence to meat safety regulations. This review covers several of meat's most widely utilized chemical decontamination agents. The conclusion suggests that future research should focus on enhancing the effectiveness of in-plant validation processes and exploring new ways to address bacterial resistance to chemical interventions.

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Applications and Efficacy of Specific Chemicals

Chlorine-Based Compounds

In many Asian countries, chlorine continues to be the most widely utilized poultry meat sanitizer (Chousalkar et al., 2019). Comparatively, chlorine has a lower cost than other sanitizers, and ease of use may get inactivated rapidly when comes in contact with meat (Sinhamahapatra and Biswas, 2021). Chlorine is an antimicrobial agent that has been shown to cause membrane permeabilization in both Gram-negative (*Yersinia enterocolitica* and *Escherichia coli*) and Gram-positive (*Salmonella*, *Listeria monocytogenes* and *Bacillus subtilis*) bacterial species (Virto et al., 2005).

Chlorine dioxide, hypochlorite, cetylpyridinium chloride (CPC), and acidified sodium chlorite (ASC) could be used as an effective alternative to chlorine (Sinhamahapatra and Biswas, 2021). Also, chlorinated compounds are often combined with organic acids, ozone, and alternative antimicrobials to improve the effectiveness of eliminating pathogens from meat surfaces (Giménez et al., 2024). There is extensive research on the use of various chlorine forms in meat decontamination, making them among the first chemical decontamination methods adopted by the meat industry. Lu et al. (2019) found that chlorine had significant reductions in *Campylobacter* loads. In a study conducted by Stivarius et al. (2002), minced beef that had been contaminated with *E. coli* and *S.* Typhimurium was treated with a solution containing 200 ppm of chlorine dioxide. The results indicated reductions in bacterial counts of 0.44 log CFU/g for *E. coli* and 0.82 log CFU/g for *S.* Typhimurium. Additionally, Ransom et al. (2003) identified lactic acid and ASC as the highest-potency antimicrobial agents available for use. McWhorter et al. (2023) compared the effectiveness of peroxyacetic acid and ASC in reducing natural microbial contamination on chicken meat, finding both treatments significantly reduce bacterial loads, with

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potential variations in efficacy depending on specific conditions. Acidifying the sodium chlorite solution with phosphoric acid led to a 3.8-3.9 log cycle reduction of both pathogens. However, Gill and Badoni (2004) noted that acidified sodium chlorite had minimal impact on reducing aerobic bacteria, coliforms, and *E. coli* on meat.

Trisodium phosphate

Trisodium phosphate (TSP) is a highly alkaline antimicrobial agent (pH 12-13) that is authorized for utilization as a spray or immersion on chicken and as a scalding agent (USDA-FSIS, 2011). For decontamination, a solution of 8% to 12% TSP could be used on poultry at temperatures between 65°-85℃ for up to 15 seconds (Alonso-Calleja et al., 2024). Alonso-Calleja et al. (2024) TSP reduced bacterial contamination in the meat and influenced the sensory properties and instrumental color of the meat, with notable effects on both appearance and texture. TSP's antimicrobial effect is owing to its ability to disrupt cell membranes and enhance the moisture solubility of bacterial DNA at elevated pH levels (Sarjit and Dykes, 2017). TSP has proven effective in eliminating and removing adhered *S.* Typhimurium from chicken following refrigeration and frozen storage (Yoon and Oscar, 2002). Cutter and Rivera-Betancourt (2000) reported that 10% TSP spray treatments were most effective in lowering *S.* Typhimurium and *E. coli* O157 on beef. Using a TSP spray or immersion alone or combined with other pathogen control methods is an effective strategy for lowering pathogenic bacteria in meat. However, challenges in using TSP include problems like handling the highly alkaline treatment solution and the risk of significant corrosion to the device and facilities due to extended contact with the decontaminant.

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Organic Acids

Research into the chemical decontamination of meat has extensively focused on using organic acids. Although the antimicrobial mechanisms of organic acids are not entirely known, it is commonly thought that the undissociated molecule plays a key role in their antimicrobial activity (Taylor and Stephanie, 2020). However, Reis et al. (2012) observed that the inhibitory effect of lactic acid on Gram-negative psychrotrophs was mainly attributed to a decline in pH instead of the existence of the undissociated molecule. The variation in antimicrobial activity among different acids suggests that multiple mechanisms of bacterial toxicity may exist (Guo et al., 2022, In et al., 2013). This indicates that the inhibitory mechanisms of organic acids could differ, and the primary antimicrobial mechanism may vary depending on the microorganism (Guo et al., 2022, In et al., 2013).

Organic acids can be found in two basic forms: pure acids and buffered acids. Pure acids include lactic, propionic, acetic, citric, and benzoic acids, while buffered organic acids are the calcium and sodium salts of propionic, acetic, citric, and benzoic acids (Wikipedia, 2005). Among the various organic acids used for meat carcass decontamination, lactic and acetic acids are the most commonly employed. Acetic acid, a monocarboxylic acid known for its strong odor and flavor, is the primary ingredient in vinegar and is mainly used for seasoning. It has a high solubility in water and is frequently present in brined foods. Acetic acid is generally recognized as safe (GRAS) for various general-purpose applications (Á lvarez-Ordóñez et al., 2010). Citric acid, a hydroxy tricarboxylic acid that occurs naturally in many plants, is water-soluble, GRAS, and authorized for use in both fresh and processed meats and poultry (USDA-FSIS, 2011). Lactic acid (2-hydroxypropanoic acid), a monocarboxylic acid with a pKa 3.79, is generated during anaerobic respiration or fermentation by various bacterial microorganisms, including lactic acid bacteria (Axelsson, 1998). It exists in two isomeric forms (D- and L-). The L isomer is

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particularly effective at inhibiting pathogens (McWilliam-Leitch and Stewart, 2002). Lactic acid is FDA-approved for use as an antimicrobial agent on meat (both pre-and post-chilling at a 5% acid solution), sub-primal cuts and trimmings (at a concentration of 2-3% and 55℃), and for washing beef heads and tongues (at concentrations of 2.0-2.8%) (USDA-FSIS, 2011).

Most of the studies conducted were on processed meat products and poultry carcasses and a few were on red meat carcasses, and the usage of organic acids on fresh carcasses during slaughter still needs to be further investigated (Aykın-Dinçer et al., 2021; Casas et al., 2021; Omori et al., 2017; Han et al., 2020). Research has indicated that acetic acid is the most effective antimicrobial against *S.* Typhimurium, with the effectiveness ranking of acetic > lactic > citric > hydrochloric (Á lvarez-Ordóñez et al., 2010). Differences in pathogen reductions may be attributed to variables like the temperature of the acid solution, ranging from room temperature to 55℃. The inability to reduce the surface pH of beef that inhibits microbial growth accounted for the lack of reduction in *E. coli* O157 counts. The efficacy of 4% L-lactic acid for decontaminating chilled carcasses was validated by Gill and Badoni (2004). Minimum inhibitory concentrations of different organic acid salts were assessed in chicken juice for *S.* Typhimurium, with sodium citrate and sodium lactate showing inhibitory effects at 1.25% concentration at 37℃ and 42℃ (Milillo and Ricke, 2010). The application of a spray containing a blend of lactic and citric acids to the chicken produced a 1.3 log CFU/ml reduction of inoculated *Salmonella* whereas immersing the chicken in the antimicrobial solution for up to 20 seconds achieved a 2.3 log CFU/ml reduction (Laury et al., 2009). Citric acid has been found to inhibit *S.* Typhimurium as effectively as acetic acid (Zhou et al., 2007). Citric acid has proven effective in controlling pathogens in fresh and processed meat. However, the use may be restricted due to potential negative sensory effects and the requirement to maintain a low pH for optimal antimicrobial activity (Zhou et al., 2007). The effectiveness of acetic acid in inhibiting *Salmonella*

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contamination can vary significantly based on concentration and specific conditions. Research indicates that acetic acid can effectively reduce microbial load at concentrations as low as 0.25%. This concentration has been shown to completely eliminate *Bacillus cereus* group, which is known to survive in refrigerated environments (Trček et al., 2015). The utility of the antimicrobial properties of lactic acid has been studied in meat. A 3.4- and 2.8-log reduction in *Salmonella* was observed on skins when 10% lactic acid was applied at 55℃ (Carlson et al., 2008). Spraying beef trim surfaces with 2.0 and 4.0% lactic acid resulted in 2.0-log and 1.5-log reductions of *E. coli* O157 and *Salmonella*, respectively (Harris et al., 2006). Özdemir et al. (2006) noted a 1.2 log CFU/g reduction of *S.* Typhimurium in beef after a 15-second immersion in hot water (82℃) combined with 2% lactic acid. Lactic acid decreased *S.* Typhimurium counts by about 2.5 log CFU/g from the initial inoculation by the 6th day of storage at 4℃, with only slight reductions noted on days 9 and 12 in vacuum-packed chicken (Over et al., 2009). In fresh sausages, deboned chicken meat treated with a 1% lactic acid solution showed a notable decontaminating effect on *Salmonella* spp. (Deumier, 2006). However, previous reports indicate minimal effectiveness of lactic acid treatment on chilled carcass surfaces, suggesting that further studies are needed to validate its use on meat.

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Bacteriocins

Bacteriocins are small, thermally stable peptides with antimicrobial properties, primarily produced by bacteria such as *Lactococcus lactis*, *Lactobacillus curvatus*, and various *Streptococcus* species (Woraprayote et al., 2016). Proteases break down these peptides and have a minimal impact on the intestinal microbiota (Woraprayote et al., 2016; Zendo, 2013). The study by Casaburi et al. (2016) demonstrates that *Lactobacillus curvatus* 54M16 is an effective starter culture for fermented sausage, producing bacteriocins that inhibit harmful bacteria, while also improving the product's safety and quality. Biscola et al. (2014) show that bacteriocin-producing *Lactococcus lactis* effectively inhibits the growth of halotolerant bacteria in Brazilian charqui. Rivas et al. (2014) investigated the bacteriocin Sakacin Q produced by *Lactobacillus curvatus* ACU-1. It examines the bacteriocin's functional properties and its effectiveness in inhibiting *Listeria* on the surface of cooked meat, showcasing its potential as a preservative in meat products.

Nisin, a bacteriocin produced by lactic acid bacteria, is the most widely utilized bacteriocin in meat applications. It is regulated by the Expert Committee of the World Food and Agriculture Organization (FDA, 2017) and is the only bacteriocin approved by the FDA as GRAS for use in meat (FDA, 2017). Several studies have explored the use of nisin for decontaminating beef. Cutter and Rivera-Betancourt (2000) reported reductions of 1.8-3.5 $\log_{10}/cm^2$ in bacterial counts on beef inoculated with different Gram-positive bacteria after treatment with a nisin solution (5000 activity units/ml). In another study, combining nisin with 50 mM ethylenediaminetetraacetic acid (EDTA) led to a reduction in counts of *S.* Typhimurium and *E. coli* O157 in buffer solutions (Cutter and Rivera-Betancourt, 2000). When applied to inoculated meat, mixtures of nisin with lactate or EDTA resulted in higher reductions compared to other combinations (Cutter and Rivera-Betancourt, 2000). Additionally, Cutter and Rivera-Betancourt (2000) found that immobilizing nisin in calcium alginate gels enhanced its inhibitory effect on *Brochothrix thermosphacta* on beef surfaces.

Tu and Mustapha (2002) demonstrated that applying nisin and EDTA to meat fully suppressed *B. thermosphacta* but had no effect on *S.* Typhimurium. Similarly, Mustapha et al. (2002) found that the effectiveness of nisin (400 U/mL) combined with 2% lactic acid in reducing *E. coli* O157 on vacuum-packaged beef was similar to that of lactic acid used by itself. Overall, the

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effectiveness of nisin and other bacteriocins such as pediocin against Gram-negative microorganisms on meat carcasses appears to be limited, unless combined with other antimicrobials. Additionally, there is limited data on the possibility of resistance occurring in organisms that come into contact with nisin.

Lactoferrin

Lactoferrin, a glycoprotein that binds iron and is present in mammalian milk and colostrum, exhibits significant antimicrobial activity against various foodborne pathogens (Montone et al., 2023). The FDA has designated lactoferrin as GRAS, and the USDA-FSIS (2011) approved its use at a 2% concentration for meat decontamination (Montone et al., 2023). Activated lactoferrin, a patented form of lactoferrin, has been suggested for use in decontaminating meat (Naidu, 2002). Activated lactoferrin is reported to disrupt microbial adhesion and colonization, removal of microorganisms from surfaces, inhibition of growth, and neutralization of endotoxins (Naidu, 2002). In one study, treating beef surfaces with a multi-step spray system that included cold water, hot water, lactic acid, and activated lactoferrin resulted in a 99.9% reduction in *E. coli* O157, compared to a 72.2% reduction when the activated lactoferrin spray was not used (Naidu, 2002). However, because activated lactoferrin is derived from milk, it could potentially trigger immunoallergic reactions in individuals sensitive to milk proteins (Naidu, 2002). Research by Soyer et al. (2020) revealed that when used together, activated lactoferrin and rosemary extract inhibited the growth of various bacteria in vitro, such as *Escherichia coli* and *Listeria monocytogenes.* There is currently limited literature on the challenges associated with activated lactoferrin and how it compares to other approved antimicrobial treatments. Additionally, information on the efficacy of lactoferrin in carcass decontamination and how it stacks up against other chemical treatments is scarce. Therefore, further research is needed to evaluate lactoferrin's potential for commercial implementation in beef carcass decontamination.

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Peracetic Acid

Peracetic acid is an organic peroxide created from a balanced blend of acetic acid, hydrogen peroxide, and water (Kitis, 2004). This compound is highly effective against a broad spectrum of pathogens, including bacteria, viruses, fungi, and spores, even when organic matter is present (Park et al., 2014; Rosario et al., 2019). Previous studies (Kalchayanand et al., 2016; Mohan and Pohlman, 2016) investigated the effectiveness of organic acids and peracetic acid as antimicrobial agents to control pathogenic *E. coli* on beef. They found that these acids could reduce the presence of the pathogen. Scott et al. (2015) evaluated the antimicrobial efficacy of a sulfuric acid and sodium sulfate blend (SSS), peroxyacetic acid (PAA), and cetylpyridinium chloride (CPC) in reducing *Salmonella* contamination on inoculated chicken wings. The results showed that all three treatments effectively reduced *Salmonella spp*. The effectiveness of SSS and PAA was comparable, indicating their potential for controlling *Salmonella* on chicken wings. Research indicates that peracetic acid outperforms chlorine and chlorine dioxide in inhibiting spoilage and improving meat safety (Olmez and Kretzschmar, 2009; Ramos et al., 2013). Its superior efficiency is because of its capacity to permeate cell membranes and break down into hydrogen peroxide and acetic acid within the cytoplasm (Kitis, 2004). The inactivation mechanism of peracetic acid involves the release of active oxygen, which oxidizes sulfhydryl groups and sulfur bonds in proteins and enzymes, ultimately causing cell death (Kitis, 2004; Srey et al., 2013). Furthermore, acetic acid lowers the cell’s internal pH, disrupting essential enzymatic activities for protein, DNA, and RNA synthesis (Srey et al., 2013). The significant ATP consumption needed to restore the cell's original pH also contributes to microbial inactivation (Theron and Lues, 2007).

Peracetic acid has several advantages as a decontaminant. It works rapidly and is effective against a broad spectrum of microorganisms (Rutala and Weber, 2013). Additionally, it is safe

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for handlers and environmentally friendly, breaking down into acetic acid and water (Park et al., 2014; Rutala and Weber, 2013). The effectiveness of peracetic acid is influenced by factors such as concentration, duration of exposure, microorganism strain, and the food matrix (Rutala and Weber, 2013).

Future Trends

Achieving completely pathogen-free meat is currently unattainable, but the application of specific chemicals to meat can significantly reduce contamination by bacteria, including harmful pathogens, thereby decreasing the risk to consumers. The ongoing development of improved meat decontamination techniques is crucial. New chemical treatments are frequently introduced, often accompanied by overstated claims related to the reduction of pathogens. Thorough scientific validation of these claims necessitates time and resources, implying the need for patented solutions often appears before substantial data is published. Future developments may focus on targeting bacteria residing beneath the meat surface due to dressing defects or small cuts in knife areas that cannot be reached by current chemical decontaminants. Therefore, ensuring contamination control after the dressing process should be a key priority. In the future, chemical decontamination efforts will likely focus on treating carcasses, trimmings, and equipment during the final phases of processing to avoid, minimize, or remove contamination. Many consumers view chemicals in meat decontamination negatively, associating them with harmful substances. To counter this, the industry and regulators should enhance transparency, educate the public on the safety of these chemicals, and emphasize their benefits in meat safety. These efforts can help correct misconceptions and build consumer trust in chemical decontamination processes.

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Conclusions

Chemical agents are effective at inactivating microorganisms. However, the effectiveness of these methods relies on various factors, such as exposure time and concentration levels of the chemical compounds. Organic acids are particularly effective antimicrobials against bacteria. Organic acids serve various advantages as antimicrobial agents since they are recognized as GRAS, have no restrictions on acceptable daily intake, are cost-effective, easy to use, and cause minimal sensory changes in meat. Therefore, it is essential to continuously optimize these methods for each type of meat matrix to minimize any physicochemical, nutritional, or sensory alterations. Additionally, the combination of different methods (hurdle concept) could improve the efficiency of decontamination. A comprehensive analysis of the optimal conditions for both individual and integrated technologies is essential to customize processes for particular meat products. This approach can assist in minimizing unwanted alterations in meat while maintaining the efficacy of decontamination.

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Table 1. Efficiency of chemical compounds in the reduction of pathogenic and spoilage microorganisms in meat.

Chemical compounds	Meat	Microorganism	Decimal reduction (log CFU) and other antimicrobial effects	Condition of application	References
Acidified sodium chlorite	Chicken	*Campylobacter*	Log 2 reduction	20 s	Chousalkar et al. (2019)
Chlorine dioxide	Minced beef	*E. coli* + *S.* Typhimurium	Reductions in bacterial counts	200 ppm	Stivarius et al. (2002)
Acidified sodium chlorite + lactic acid	Beef	*E. coli* O157:H7	Reductions in bacterial counts	2% lactic acid + 0.02% acidified sodium chlorite	Ransom et al. (2003)
Peroxyacetic acid + acidified sodium chlorite	Chicken	*Campylobacter* + *Salmonella*	Reductions in bacterial counts	100 ppm peroxyacetic acid + 225 ppm acidified sodium chlorite	McWhorter et al. (2023)
Trisodium phosphate	Beef	*E. coli* O157:H7 + *Salmonella* Typhimurium	Reductions in bacterial counts	10% Trisodium phosphate spray treatments	Cutter and Rivera-Betancourt (2000)
Trisodium phosphate	Rabbit	Total aerobic counts	Reductions in bacterial counts	8% Trisodium phosphate for up to 15 s	Alonso-Calleja et al. (2024)
Trisodium phosphate	Chicken	*S.* Typhimurium	Reductions in bacterial counts	10% Trisodium phosphate	Yoon and Oscar, (2002)
Lactic acid	Beef	*E. coli*	Log 2 reduction	0.02% peroxyacetic acid + acidified 0.16% sodium chlorite + 2% lactic acid	Gill and Badoni (2004).
Lactic + citric acids	Chicken	*Salmonella*	2.3 log CFU/ml reduction	Immersing containing a blend of lactic + citric acids for up to 20 seconds	Laury et al. (2009)
Lactic + citric acids	Chicken	*Salmonella*	1.3 log CFU/ml reduction	Spray containing a blend of lactic + citric acids	Laury et al. (2009)
Lactic acid	Chicken juice	*Salmonella*	Reductions in bacterial counts	4% lactic acid	Milillo and Ricke, (2010)
Lactic acid	Turkey breast	*S.* enterica	Reductions in bacterial counts	3% lactic acid	Aykın-Dinçer et al. (2021)

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Lactic acid	Beef	*E. coli* O157:H7 and *Salmonella*	Reductions in bacterial counts	2-5% lactic acid	Casas et al. (2021)
Lactic acid	Beef	Total viable counts	Reduction of the total viable counts to less than 2 log CFU	Spraying with 2%, 3%, 4% lactic acid	Han et al. (2020)
Lactic acid	Beef	*Salmonella*	3.4- and 2.8-log reduction	10% lactic acid	Carlson et al. (2008)
Lactic acid	Beef	*E. coli* O157 and *Salmonella*	2.0-log and 1.5-log reductions	Spraying with 2%, 4% lactic acid	Harris et al. (2006)
Lactic acid	Beef	*S.* Typhimurium and *Listeria monocytogenes*	1.2 log CFU/g reduction	15 s immersion in hot water (82℃) + 2% lactic acid	Ö zdemir et al. (2006)
Lactic acid	Chicken	*S.*	reductions in bacterial counts	1% lactic acid solution	Deumier (2006)
Bacteriocins	Fermented sausage	*L. monocytogenes, B. cereus* and *Lactobacillus* spp	Inhibition of bacterial growth	Inoculation of L. curvatus 54M16	Casaburi et al. (2016)
Bacteriocins	Charque meat	Microbiological diversity	Decrease of deterioration potential	Inoculation of L. lactis subsp. lactis 69	Biscola et al. (2014)
Bacteriocins	Cooked meat	L. innocua	Decrease of bacterial growth	Sakacin Q produced by inoculated L. curvatus ACU-1	Rivas et al. (2014)
Nisin	Beef	*S.* Typhimurium and *E. coli* O157	Reductions of 1.8-3.5 $\log_{10}/cm^2$ in bacterial counts	Nisin + 50 mM ethylenediaminetetraacetic acid (EDTA)	Cutter and Rivera-Betancourt (2000)
Nisin	Beef	*B. thermosphacta*	Decrease of bacterial growth	Nisin + 50 mM ethylenediaminetetraacetic acid (EDTA)	Tu and Mustapha (2002)
Nisin+ lactic acid	Beef	*E. coli* O157	Decrease of bacterial growth	Nisin + 2% lactic acid	Mustapha et al. (2002)
Activated lactoferrin	Beef	*E. coli* O157:H7, *S.* Enteritidis and *L. monocytogenes*	2 log CFU/g reduction in *L. monocytogenes*	4% Activated lactoferrin	Soyer et al. (2020)
Peracetic acid	Beef	*E. coli* O157:H7 Mesophilic bacteria Coliform counts	1.0/g 0.2/g 0.2/g	20 mg/L, rinsing for 15 s	Mohan and Pohlman (2016)
Peracetic acid	Beef	*E. coli* O26:H11/3392 *E. coli* O157:H7 *S.* Typhimurium	5.8/mL 3.5/mL 3.6/mL	200 mg/L, 300 s	Kalchayanand et al. (2016)

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Peracetic acid	Chicken	Mesophilic bacteria and *Salmonella* strains	1.5/mL	700 mg/L, 20 s	Scott et al. (2015)

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