Egyptian Journal of Animal Health

P-ISSN: 2735-4938 On Line-ISSN: 2735-4946
Journal homepage: https://ejah.journals.ekb.eg/

Synergistic effect of oxidized electrolyzed water and fumaric acid for control of some species of *Salmonella* enterica in beef.

Asmaa Elsayed Mohammed*, Nahed Mahmoud Abdelaziz**

*Department of Bacteriology, Animal Health Research Institute, Agriculture Research Center (ARC), Sohag, Egypt.
** Department of Food Hygiene (Meat Hygiene), Faculty of Veterinary Medicine, Sohag University, Sohag, Egypt.

Received in 8/1/2025
Received in revised from 28/1/2025
Accepted in 2/3/2025

Keywords:
Salmonella,
beef,
slightly acidic electrolyzed water,
fumaric acid

ABSTRACT

Salmonella is the common reason of foodborne concern in meat and meat products worldwide. Chemical sanitizers as fumaric acid (FA) and the slightly acidic electrolyzed water (SAEW) can reduce microbial contaminations which reflected on the quality and microbial safety of beef. The current study was performed to determine the synergetic impact of 1% FA and SAEW 30 mg/L for the deactivation of both *Salmonella* enteritidis and *Salmonella* virchow previously isolated from meat. A two-kilogram beef sample was divided into two portions, each inoculated with a different *Salmonella* strain: *S.* virchow and *S.* enteritidis, both of 10^6 CFU/ml. Each portion was subdivided into four groups; group A (positive control), group B (treated with SAEW 30 mg/L pH 6 for five minutes), group C (treated with FA 1% for five minutes), and group D (treated with SAEW 30 mg/L for five minutes then FA 1% for five minutes). Results indicated that SAEW 30mg/L caused a log reduction of 1.94 log cfu/g (30.9%) and 2.15 log cfu/g (33.3%) in *S.* virchow and *S.* enteritidis respectively. While 1% FA yielded a log reduction of 1.69 log cfu/g (26.9%) in *S.* virchow and 1.83 log cfu/g (28.5%) in *S.* enteritidis. On the other hand, the incorporation of SAEW 30 mg/L and 1% FA led to a log reduction of 2.93 log cfu/g (46.7%) and 3.14 log cfu/g (48.7%) in *S.* virchow and *S.* enteritidis respectively. No noticeable changes in the odor, color, texture, pH and overall appearance (OAA) of beef specimens inoculated with *S.* virchow or *S.* enteritidis after treatment with sanitizing agents in comparison to the control groups. SAEW 30 mg/L and 1% FA have strong bactericidal activity against *Salmonella* spp. The integrated treatment by SAEW and 1% FA exhibited a greater bactericidal impact and significantly reduced the *Salmonella* count in meat compared to single treatments. Despite the strong effect of the electrolyzed water and fumaric acid compound, these compounds were unable to completely eliminate *Salmonella* bacteria, which is considered one of the basic requirements for any food standard specification.

Corresponding author: Asmaa Elsayed Mohammed, Department of Bacteriology, Animal Health Research Institute, Agriculture Research Center (ARC), Sohag, Egypt.
Email address: dr_asmaa_lab@yahoo.com
DOI: 10.21608/ejah.2025.416803

INTRODUCTION

Because of its rich nutrient content, meat plays a crucial role in a healthy, balanced diet. It is a principal origin of proteins, iron, vitamins, and trace elements **(Pereira and Vicente 2013).**

Despite its benefits, meat may harbor some foodborne pathogens that can be hazardous to humans depending on the concentration of microorganisms and consumer resistance. Foodborne pathogenic organism contaminating meat and its products has been a challenging public health issue for many years **(Ehuwa, Jaiswal, and Jaiswal 2021)**.

The steps of processing, transportation, and preservation could be implemented in contamination of meat and meat products. Meat has a high water content, making it agoo d media for contamination by a wide range of microorganisms. *Salmonella* enterica endures to be the most common bacterial pathogen causing foodborne illness **(Control and Prevention 2009)**. *Salmonella* was encountered as the prime causative pathogen in the majority of notified foodborne outbreaks affecting people in the European Union countries **(Popa and Papa 2021)**. Various chemical disinfectants were investigated to control microbial contamination, extend shelf life, and ameliorate the microbiological safety and quality of meat during processing and storage **(Lee and Yoon 2021)**. Electrolyzed water (EW), chlorinated solutions, salts, and organic acids, alone or in integration were able to minimize microbial contaminations of meat **(Chen et al. 2012)**.

Electrolyzed water (EW) was documented to have a potent bactericidal action against most pathogenic microorganisms and was approved as a safe, rapid green technology that can be produced on-site. It is low cost antimicrobial treatment so would be economic **(Jadeja and Hung 2014)**. Electrolyzed water is induced by running an electric current via a diluted solution of salt water by usage of membrane cell to yield a strong acidic electrolyzed water, while non-membrane cells output slightly acidic electrolyzed water (SAEW), with dilute hypochloric acid. SAEW, with an available chlorine concentration between 10 and 30 mg/L and a pH level of 5.0 to 6.5, is approved by the Japanese Ministry of Health and Welfare as a safe food sanitizer **(Suzuki et al. 2002)**. Because SAEW has a low content of chlorine, its use reduces the processing equipment's corrosion and skin irritation. Consequently, it's recognized as an eco-friendly sanitizer in parallel to other conventional chemical alternatives **(Kim, Hung, and Brackett 2000)**.

Electrolyzed water comes in two main types, defined by their pH: strongly acidic (pH 2.2–3.5) and slightly acidic (pH 5.0–6.5). Slightly acidic electrolyzed water (SAEW), with its near-neutral pH, primarily contains hypochlorous acid (HOCl), which is a far more potent sanitizer than hypochlorite ions at the same concentration about 80 times **(Kim, Hung, and Brackett 2000)**.

SAEW sanitization efficacy has been documented to successfully deactivate foodborne pathogens such as *Salmonella* spp. on variable agricultural products, involving vegetables and fruits **(Forghani and Oh 2013)** in addition to beef, egg, and poultry meat **(Jadeja and Hung 2014)**. It has also been documented as an effective disinfectant of the surfaces of different food processing utensils **(Deza, Araujo, and Garrido 2005)**.

Organic acids are broadly utilized in food manufacturing as chemical preservatives. They proved to have antibacterial action across wide scope of food types and are globally accepted as safe for human consumption **(Mani-López, García, and López-Malo 2012)**. The advantage of organic acids' addition as antimicrobial substances in food products relies on some vital parameters such as their chemical formula, molecular weight, physical form, and minimum inhibitory concentration. Other factors include the virulence of the pathogen, acid -food contact time and buffering criteria of the food. In the meat industry, meat dipping into a solution containing organic acid improves fresh meat color and stability and maintains the brightness and extend the meat shelf-life **(Coban 2020)**.

Fumaric acid (FA) is considered one of popular organic acids used as antimicrobial additives in meat. It possesses a potent killing action against foodborne bacteria. Fumaric acid is mostly defined as safe by the FDA and is asserted for use in many countries **(He et al. 2020)**. Fumaric acid demonstrates antimicrobial efficacy in meat preservation, effectively minimizing bacterial populations and extending shelf-life. Therefore, while FA can be a valuable component in meat preservation strategies, its concentration and application methods should be carefully optimized to balance microbial safety with the maintenance of desirable meat quality attributes **(Zhao et al. 2022)**. Therefore, the current study was carried out to assess the synergetic effect of SAEW 30 mg/L and 1% FA for the inactivation of *Salmonella* enteritidis and *Salmonella* virchow previously isolated from meat.

MATERIAL AND METHODS

This work was performed from October 2024 to January 2025 in the Bacteriology Department, Animal Health Research Institute, Sohag branch.

Preparation of bacterial cultures

S. enterica subspecies enterica serovar virchow, and *S.* enterica subspecies enterica serovar enteritidis, previously recovered from meat samples were obtained from the Department of Bacteriology, Animal Health Research Institute. Each strain was subcultured onto tryptic soy agar (Oxoid) plates and incubated for twenty four hours at 37 °C. Colonies (3-4) were picked up and inoculated in tryptic soy broth (Oxoid) and then incubated for 2-6 hours at 37 °C. Suspension turbidity was balanced to coordinate with 0.5 McFarland standards and then diluted to get a concentration of 10^6 CFU / ml approximately **(Tango et al. 2014)**.

Preparation of sanitizing solutions

SAEW 30 mg/L employed in our study was brought from the Faculty of Science, Sohag University, Egypt. It was prepared by electrolysis of 6% Hydrochloric acid solutions via an electrolysis apparatus with pH 5.0–6.5. The crystalline FA (Anmol Chemicals Co., USA) was dissolved in one liter of deionized water to obtain a conc. of 1% FA solution (w/v), stored at 50˚C from preparation and during the experiment time to avoid its precipitation. The oxidation-reduction potential (ORP) and pH of SAEW and FA were assessed with adual-scale pH meter (PHS-3DW, Labitex, China) holding pH and ORP electrodes. A colorimetric method was used to determine the available chlorine conc. (ACC) via a digital chlorine assay kit (AE86060, Labitex, China). The detection border was 1-300 mg/L. The physic-chemical characteristics of the examined antimicrobial sol. are listed in Table A.

Table A. The physicochemical characteristics of the antimicrobial substances.

	pH **	ORP **	ACC **
SAEW	6.14 ± 0.067	821.1 ± 7.492	30.03 ± 0.149
1%FA	2.60 ± 0.064	590.3 ± 7.382	ND
SAEW+1%FA	2.93 ± 0.054	1086 ± 5.707	15.8 ± 0.369

**High statistical significant differences between the different treatments according to pH (Kruskal-Wallis statistic= 18.59, p=0.001), ORP (F= 8553, p=0.0001), ACC (t=101.2, p=0.001), and ND means not detected.

Collection and preparation of samples

Two kilograms of boneless beef samples was purchased from butcher shops in Sohag City in clean sterile bags and transported immediately to the laboratory in ice boxes to be prepared and examined as soon as possible. Sample was divided into pieces using a sterile knife. Aliquots weighing 10 ± 0.3 gm were used for the *Salmonella* count, and those weighing 25 ± 0.3 gm were used for measuring the pH value and sensory analysis.

Prior to the experiments, the meat surface was subjected to ultraviolet light (UV) and emitted at 254 nm for 15 min to reduce background microflora **(Mansur et al. 2015)**. Beef samples were divided into two portions, the first portion was inoculated with *S.* virchow, and the second one was inoculated with *S.* enteritidis with a conc. of 10^6 CFU /ml each. The inoculated beef samples were left for one hour at room temperature to help adherence of bacteria, and then subjected to the employed treatments. Each portion was subdivided into four groups; group A (positive control), group B (treated with SAEW 30 mg/L pH 6 for five minutes), group C (FA 1% for five minutes), and group D (SAEW 30 mg/L for five minutes then FA 1% for five minutes).

Thereafter, each 10 g beef sample was mixed with ninety milliliter of buffered peptone water (BPW) (Oxoid) and homogenized for two minutes in a Sward stomacher (400 Circulator, Seward, London, US). After that, to enumerate *Salmonella* spp., ten-fold serial dilutions from the four meat groups were prepared using BPW, and 0.1 mL of diluents were spread onto XLD agar (Oxoid) plates. The inoculated plates were incubated at 37 °C for twenty four hours and then *Salmonella* count was recorded. Each autonomous trial was in triplicates **(Hantash et al. 2020)**.

pH measurement:

pH was measured according to **(Feldsine, Abeyta, and Andrews 2002)**.To determine pH, ten grams beef sample was blended with one hundred milliliters DW and then filtered. The pH of the resulted filtrate was measured using a Crison pH meter (Model 507, Crison, Barcelona, Spain) with combination electrode (Cat. n°. 52, Crison, Barcelona, Spain) previously calibrated with buffers, pH 7 and 4.

Sensory assessment

According to **(Turner et al. 2019),** the organoleptic examination of beef was performed for odor, color, texture, pH and overall and overall acceptability with the help of the Animal Health Research Institute, Sohag branch committee composed of11staff members. The scale points range was graded as poor (1) acceptable (2), good (3), very good (4), and excellent (5).

Statistical analysis

Data represented as mean, median , and standard deviation of the log mean (SD), the analysis of variables were achieved using MedCalc® Statistical Software version 20 (MedCalc Software Ltd, Ostend, Belgium; 2021). To value whether the data met the suppositions of the statistical approach, the Shapiro-Wilk normality test was used, while Levene's test was used to assess the Homogeneity of Variance Test.

Ordinary ANOVA test with Conover Multiple Comparison Test for Post hoc (no normality in data distribution) were used to elucidate the significant variations between the groups. Obtained data were deemed statistically significant if the p-value was below 0.05, and highly significant if it was below 0.01 **(Lantz, Andersson, and Manfredsson 2016)**.

RESULTS

The initial count of *S.* virchow and *S.* enteritidis in beef samples used to evaluate the sanitizing efficiency of examined treatments sole or in together were approximately 6.27 and 6.42 log cfu/g. Antimicrobials significantly reduced the pathogen ($P < 0.0001$) to 4.33 and 4.28 log cfu/g of *S.* virchow and *S.* enteritidis when treated with SAEW 30 mg/L, and to 4.58 and 4.59 log cfu/g, when dealed with 1% FA, and to 3.34 and 3.29 log cfu/g when treated with the integration of SAEW 30 mg/L and 1% FA (Table 1).

Table 1. Effect of antimicrobials on *S.* virchow and *S.* enteritidis mean counts (log cfu/g± SD).

Experiment Group	*S.* virchow		*S.* enteritidis	
	Mean	SD	Mean	SD
Control	6.27[a]	±0.020	6.42[a]	±0.010
SAEW	4.33[b]	±0.061	4.28[b]	±0.045
1% FA	4.58[b]	±0.040	4.59[b]	±0.015
SAEW + 1% FA	3.34[c]	±0.086	3.29[c]	±0.031

There are a significance difference (P < 0.05) between means having a different superscripted small letters.

SAEW 30mg/L caused a log reduction of 1.94 log cfu/g (30.9%) and 2.15 log cfu/g (33.3%) in *S.* virchow and *S.* enteritidis, while 1% FA yielded a log reduction of 1.69 log cfu/g (26.9%) and 1.83 log cfu/g (28.5%) in *S.* virchow and *S.* enteritidis respectively. The incorporation of SAEW 30 mg/L and 1% FA lead to a log reduction of 2.93 log cfu/g (46.7%) and 3.14 log cfu/g (48.7%) in *S.* virchow and *S.* enteritidis respectively (Table 2).

Table 2. Log reduction and percentage of *S.* virchow and *S.* enteritidis treated with different agents.

Antimicrobial agents	*S.* virchow		*S.* enteritidis	
	Log Reduction			
	Rate	%	Rate	%
SAEW	1.94	30.9%	2.15	33.3%
1%FA	1.69	26.9%	1.83	28.5%
SAEW + 1% FA	2.93	46.7%	3.14	48.7%

No noticeable changes in the odor, pH and OAA of beef specimens inoculated with *S.* virchow or *S.* enteritidis after treatment with sanitizers in comparison to the control. Groups treated with sanitizing agents presented a more clearly intense pinker color than the control group. Regarding the texture, treatments produced a slight rise in firmness and work of cutting (table 3).

Regarding *S.* virchow, there were no statistically significant variations among the different treatments according to the pH of the samples (F= 0.3889, p=0.76). No statistically significant variations among the different treatments according to the texture (Kruskal-Wallis statistic= 4.087, p=0.252 (table 3).

Regarding *S.* enteritidis, there were no statistically significant variations among the different treatments according to the pH of the samples (F= 0.99, p=0.411). There were no statistically variations among the different treatments according to the texture (Kruskal-Wallis value = 3.231, p=0.357), the odor of the samples (3.591, p=0.309), the color of the samples (1.091, p=0.779), and the overall acceptability (0.352, p=0.95) (table 3).

Table 3. Sensory attributes of control and treated beef samples contaminated with *S.* virchow and *S.* enteritidis.

Salmonella spp.	Experiment Group	pH	Texture	Odor	Color	OAA
S. virchow	Control	5.20 ±0.131	4.3 ±0.823	3.9 ±0.738	3.9 ±0.738	3.9 ±0.568
	SAEW	5.20±0.076	3.8 ±0.789	4.3 ±0.823	4.2 ±0.789	4.1 ±0.876
	1%FA	5.25±0.151	3.6 ±0.699	4.3 ±0.823	4.4 ±0.699	4.4 ±0.699
	SAEW+FA	5.25±0.151	3.8 ±0.789	4.3 ±0.823	4.3 ±0.823	4.2 ±0.789
S. enteritidis	Control	5.16 ±0.106	4.1 ±0.876	4 ±0.667	4.1 ±0.738	4.2 ±0.632
	SAEW	5.24±0.119	4 ±0.816	4.5 ±0.707	4.4 ±0.843	4.1 ±0.876
	1%FA	5.26±0.141	3.6 ±0.699	4.5 ±0.707	4.2 ±0.789	4.3 ±0.823
	SAEW+FA	5.25±0.141	4.2 ±0.789	4.3 ±0.823	4.3 ±0.823	4.2 ±0.789

DISCUSSION

Food safety threats posed by food-borne infections, such as *Salmonella*, continue to be of great concern for the industry of food. Diseases caused by *Salmonella* are major public health issues and more important worldwide in developing countries **(Wang et al. 2008)**.

Many sanitizers, as SAEW, FA, hydrogen peroxide, chlorine dioxide, and sodium hypochlorite have been widely employed for their efficacy in decreasing or eliminating pathogenic microorganisms in food manufacturing **(Koide et al. 2011)**.

SAEW has an effective bactericidal action based on its low pH, high ORP values, and high ACC values. **Huang et al. (Huang YuRu et al. 2008)** concluded that ACC has substantial role in the bactericidal impacts of SAEW more than other factors as high ORP and low pH value. ACC values are associated with available chlorine which contributes primarily to HOCl, which is a potent antimicrobial substance **(Cao et al. 2009)**. HOCl penetrates microbial cell walls, disrupting proteins, DNA, and enzymes, leading to cell death. The high ORP of SAEW enhances its capability to destroy bacterial cell membranes and denature critical cellular components. The acidic nature of SAEW can destabilize the bacterial cell wall and membrane, increasing the efficacy of its oxidative agents **(Meghwar et al. 2024)**.

In this study,. the use of SAEW led to a log reduction of 1.94 log cfu/g (30.9%) and 2.15 log cfu/g (33.3%) in *S.* virchow and *S.* enteritidis. Higher data were gained by **(Bing et al. 2022)** who mentioned that treatment of beef samples with SAEW results in a log reduction of 3.36 log CFU/g in case of *S.* enteritidis. Similar results were reported by **(Rahman et al. 2012)), (Al-Holy and Rasco 2015), and (Mansur et al. 2015))** who reported a log reduction of 2.99, 2.3, and 1.6 log CFU/g in *S.* typhimurium when treated with SAEW.

Sanitization effectiveness of SAEW has been confirmed in eliminating *Salmonella* on a variety of foods, including fresh vegetables and fruits as well as meats; beef and pork **(Kim, Hung, and Russell 2005)**, poultry and eggs **(Fabrizio et al. 2002)**, and seafood **(Ozer and Demirci 2006)**. SAEW has also demonstrated as a surface disinfectant for numerous food processing utensils **(Deza, Araujo, and Garrido 2005)**.

Fumaric acid has antimicrobial effects against *Salmonella* spp. The undissociated form of fumaric acid can cross the cell membrane of bacteria, disrupt intracellular pH and metabolic functions. Also, it can interfere with bacterial energy metabolism by targeting enzymes or pathways crucial for *Salmonella* survival and growth **(ABDEL-WAHHAB et al. 2023)**.

Through the current study, the use of 1% FA led to a log reduction of 1.69 log cfu/g (26.9%) and 1.83 log cfu/g (28.5%) in *S.* virchow and *S.* enteritidis respectively. Many reports confirmed the effectiveness of using FA for minimizing *Salmonella* on fresh beef surfaces. Many studies; **Podolak et al. (1995, 1996)** mentioned the reduction of this microbe was less than 2 log CFU/g and that supported by **(Fabrizio and Cutter 2004; Podolak et al. 1995, 1996) and (Rahman, Wang, and Oh 2013)**.

In the present work, the combination of 1% FA and SAEW 30 mg/L resulted in a log reduction of 3.14 log cfu/g (48.7%) and 2.93 log cfu/g (46.7%) in *S.* enteritidis and *S.* virchow. Numerous studies reported that the incorporation of SAEW 30 mg/L and 0.5% FA was associated with greater decreases of pathogens paralleled to control and all sole treatments ($P < 0.05$), which minimized *S.* typhimurium by 2.6 and 2.99 log CFU/g **((Mansur et al. 2015)**.

The synergetic bactericidal impact of SAEW and FA might be attributed to the enhanced physicochemical characteristics of both sanitizers. The addition of FA to SAEW decreases the ACC and pH values of SAEW and increases its ORP value. The integrated action of ACC, chlorine compound, pH, and stable molecules of 1% FA and SAEW can explain their boosted bactericidal efficacy in the minimizing of pathogens in fresh beef. Undissociated forms of FA may act as a permeabilizer of the cell membrane of bacteria and react as a potentiator of the impacts of SAEW to boost its antimicrobial action. The sequential antimicrobial application of SAEW and 1% FA was more efficient in the reduction of microbial contamination in meat fatty tissue than sole sanitizing treatments **(Pohlman et al. 2002)**. Furthermore, the lower chlorine concentration in the combined treatment enhances its safety and makes it more suitable for meat industry applications. **Byelashov and Sofos (2009)** have approved chlorine conc. at 20 mg/L for poultry sprays and washes in the United States.

In general, the application of sanitizer treatments can decrease the bacterial contamination load but does not completely eradicate pathogens. Multiple causes that can influence microbial responses to disinfection include initial microbial load, treatment conditions, low-nutrient growth, adherence to surfaces, aggregation and encapsulation. Increased resistance to disinfection can be attributed to the adherence or association of microorganisms to diverse particulate surfaces. Therefore, before the selection and application of a food sanitizing technique, it is crucial to know the kind of organism being goaled and its linked resistance to the selected technique **(Sun et al. 2022)**.

The present study revealed that S. virchow is more resistant to treatment by sanitizers than S. enteritidis. **(Yoon et al. 2017)** mentioned that *S. virchow* is generally considered **more virulent** than *S. enteritidis* due to its **higher invasiveness, and antibiotic resistance.**

In the present study, no noticeable changes in the OAA, odor, and pH of beef specimens inoculated with *S.* virchow or *S.* enteritidis after treatment with sanitizing agents in comparison to the control. Groups treated with sanitizing solutions presented a more clearly intense pinker color than the control group. Regarding the texture profile FA treatments caused a slight increase in firmness and work of shear. Similar data were obtained by **(Sheng et al. 2018)**, **(Naka et al. 2020)**, **(Biswas et al. 2024)** who demonstrated that SAEW has no effect on the sensory properties of beef samples.

(Rahman et al. 2012) reported that SAEW treatment can improve sensory properties. It contains HOCl and −OH that have potent antimicrobial and antioxidant effects that help to keep oxidation stability with SAEW-washed meat specimens better than control ones. Furthermore, the residual hydrochloric acid content of SAEW (although minute) preserves meat odor and gives meat specimens a fresh color.

Fumaric acid helps stabilize myoglobin, which responsible for meat's red color enhances the formation of oxymyoglobin by reducing oxidation and lowering pH, it slows down discoloration and helps retain the bright red color longer as mentioned by **Hecer and Guldas (2011), (Gómez et al. 2020) and (Shi et al. 2022)**, **and (Vila-Clarà et al. 2024)**, (Hecer and Guldas 2011) reported that no color loss and no impact was seen on odor obtained with the application of 1% FA after slaughtering. **(Fernández et al. 2021)** reported that FA lowers pH, which can cause protein denaturation and result in a firmer texture.

CONCLUSION

None of the tested antimicrobial agents completely eliminated *Salmonella* contamination (serovars enteritidis and virchow). Reduction rates varied between the two agents evaluated (electrolyzed water and fumaric acid). Further research is needed under a range of conditions and with additional *Salmonella* strains to investigate the influence of genetic variations on antimicrobial resistance. This should include exploring higher concentrations of the tested disinfectants, evaluating alternative disinfectants, or investigating synergistic effects by combining them with other antimicrobial agents. Crucially, any such agents must demonstrate potent antimicrobial activity while ensuring consumer safety and minimizing environmental impact.

REFERENCES

Abdel-wahhab reham mervat elbarbary amina el-amin and soad el-sheikh. 2023. 'effect of some organic acids on salmonella typhimurium in chicken meat , *Assiut Veterinary Medical Journal*, (69): 112-21.

Al-Holy Murad A, Barbara A, Rasco. 2015. 'The bactericidal activity of acidic electrolyzed oxidizing water against Escherichia coli O157: H7, Salmonella Typhimurium, and Listeria monocytogenes on raw fish, chicken and beef surfaces', *Food Control*, (54): 317-21.

Bing Shan Yitian Zang Yanjiao Li, Beibei Zhang Qingnan Mo, Xianghui Zhao, Chen Yang. 2022. 'A combined approach using slightly acidic electrolyzed water and tea polyphenols to inhibit lipid oxidation and ensure microbiological safety during beef preservation', *Meat Science*, (183): 108643.

Biswas Gourpada Md, Shafiqul Islam SM, Mahbubur Rahman SM, Abdullah Al Mamun. 2024. 'EFFECT OF ELECTROLYZED WATER ON PHYSICO-CHEMICAL AND SENSORY QUALITIES OF BEEF', *Теория и практика переработки мяса*, (9): 180-87.

Cao, Wei, Zhi Wei Zhu, Zheng Xiang Shi, Chao Yuan Wang Bao Ming Li. 2009. 'Efficiency of slightly acidic electrolyzed water for inactivation of Salmonella enteritidis and its contaminated shell eggs', *International Journal of Food Microbiology*, (130): 88-93.

Chen, JH, Y, Ren J, Seow T, Liu WS ,Bang HG, Yuk. 2012. 'Intervention technologies for ensuring microbiological safety of meat: current and future trends', *Comprehensive Reviews in Food Science and Food Safety*, (11): 119-32.

Coban, Hasan Bugra. 2020. 'Organic acids as antimicrobial food agents: applications and microbial productions', *Bioprocess and Biosystems Engineering*, (43): 569-91.

Control, Centers for Disease, Prevention. 2009. 'Preliminary Food Net Data on the incidence of infection with pathogens transmitted commonly through food--10 States, 2008', *MMWR: Morbidity & Mortality Weekly Report*, 58.

Deza, MA, M, Araujo MJ, Garrido. 2005. 'Inactivation of Escherichia coli, Listeria monocytogenes, Pseudomonas aeruginosa and Staphylococcus aureus on stainless steel and glass surfaces by neutral electrolysed water', *Letters in applied microbiology*, (40): 341-46.

Ehuwa Olugbenga Amit K, Jaiswal Swarna Jaiswal. 2021. 'Food Safety and Food Handling Practices'.

Fabrizio KA, CN, Cutter. 2004. 'Comparison of electrolyzed oxidizing water with other antimicrobial interventions to reduce pathogens on fresh pork', *Meat Science*, (68): 463-68.

Fabrizio KA, RR, Sharma A, Demirci CN, Cutter. 2002. 'Comparison of electrolyzed oxidizing water with various antimicrobial interventions to reduce Salmonella species on poultry', *Poultry science*, (81): 1598-605.

Feldsine Philip Carlos Abeyta Wallace H, Andrews. 2002. 'AOAC International methods committee guidelines for validation of qualitative and quantitative food microbiological official methods of analysis', *Journal of AOAC international*, (85): 1187-200.

Fernández Mariano Anabel Rodríguez, Micaela Fulco, Trinidad Soteras, Marina Mozgovoj and Mariana Cap. 2021. 'Effects of lactic, malic and fumaric acids on Salmonella spp. counts and on chicken meat quality and sensory characteristics', *Journal of Food Science and Technology*, (58): 3817-24.

Forghani Fereidoun and Deog-Hwan Oh. 2013. 'Hurdle enhancement of slightly acidic electrolyzed water antimicrobial efficacy on Chinese cabbage, lettuce, sesame leaf and spinach using ultrasonication and water wash', *Food Microbiology*, (36): 40-45.

Gómez Inmaculada Rasmi Janardhanan, Francisco C, Ibañez María José Beriain. 2020. 'The effects of processing and preservation technologies on meat quality: Sensory and nutritional aspects', *Foods*, (9): 1416.

Hantash Tariq Maarten Nauta, Mohammad Nafi Solaiman Al-Sabi Walid Q Al-Ali, and Hakan Vigre. 2020. 'The “rapid’Salmonella” Method: Estimation of the limit of detection for Salmonella strains Typhimurium and Enteritidis isolated from frozen poultry meat', *Modern Applied Science*, (14): 43-51.

He, S, J, Ding Y, Xiong, D, Liu, S, Dai H, Hu. 2020. 'Effects of dietary fumaric acid on growth performance, meat quality, nutrient composition and oxidative status of breast muscle in broilers under chronic heat stress', *European Poultry Science/ Archiv für Geflügelkunde*, 84.

Hecer Canan METİN Guldas. 2011. 'Effects of lactic acid, fumaric acid and chlorine dioxide on shelf-life of broiler wings during storage', *Afr. J. Microbiol. Res*, (23): 3880 -83.

Huang YuRu, Huang YuRu, YC, Hung, Hsu Shun Yao Hsu Shun Yao, Huang Yao Wen Huang Yao Wen, Hwang Deng Fwu Hwang Deng Fwu. 2008. 'Application of electrolyzed water in the food industry'.

Jadeja Ravirajsinh and Yen-Con Hung. 2014. 'Efficacy of near neutral and alkaline pH electrolyzed oxidizing waters to control Escherichia coli O157: H7 and Salmonella Typhimurium DT 104 from beef hides', *Food Control*, (41): 17-20.

Kim, C, YC, Hung SM, Russell. 2005. 'Efficacy of electrolyzed water in the prevention and removal of fecal material attachment and its microbicidal effectiveness during simulated industrial poultry processing', *Poultry science*, (84): 1778-84.

Kim, Chyer Yen Con Hung Robert E, Brackett. 2000. 'Efficacy of electrolyzed oxidizing (EO) and chemically modified water on different types of foodborne pathogens', *International Journal of Food Microbiology*, (61): 199-207.

Koide Shoji, Douglas Shitanda Mizuho Note Wei Cao. 2011. 'Effects of mildly heated, slightly acidic electrolyzed water on the disinfection and physicochemical properties of sliced carrot', *Food Control*, (22): 452-56.

Lantz, Björn, Roy Andersson Peter Manfredsson. 2016. 'Preliminary tests of normality when comparing three independent samples', *Journal of Modern Applied Statistical Methods*, (15): 135-48.

Lee, Heeyoung Yohan Yoon. 2021. 'Etiological agents implicated in foodborne illness world wide', *Food science of animal resources*, (41): 1.

Mani-López E, HS, García Aurelio López-Malo. 2012. 'Organic acids as antimicrobials to control Salmonella in meat and poultry products', *Food Research International*, (45): 713-21.

Mansur Ahmad Rois Charles Nkufi Tango

Gwang-Hee Kim Deog-Hwan Oh. 2015. 'Combined effects of slightly acidic electrolyzed water and fumaric acid on the reduction of foodborne pathogens and shelf life extension of fresh pork', *Food Control*, (47): 277-84.

Meghwar Parkash Syed Muhammad Ghufran Saeed, Lucrezia Forte Slim Smaoui Nurul Izzah Khalid Pasquale De Palo and Aristide Maggiolino. 2024. 'Electrolyzed Water: A Promising Strategy for Improving Food Quality and Safety of Fruits, Vegetables, and Meat', *Journal of Food Quality*, (2024): 3272823.

Naka Angelica Masaya Yakubo Kenji Nakamura Midori Kurahashi. 2020. 'Effectiveness of slightly acidic electrolyzed water on bacteria reduction: in vitro and spray evaluation', *PeerJ*, (8): e8593.

Ozer Nil P, Ali Demirci. 2006. 'Electrolyzed oxidizing water treatment for decontamination of raw salmon inoculated with Escherichia coli O157: H7 and Listeria monocytogenes Scott A and response surface modeling', *Journal of Food Engineering*, (72): 234-41.

Pereira Paula Manuela de Castro Cardoso, and Ana Filipa dos Reis Baltazar Vicente. 2013. 'Meat nutritional composition and nutritive role in the human diet', *Meat science*, (93): 586-92.

Podolak RK, JF, Zayas CL, Kastner DYC Fung. 1995. 'REDUCTION OF LISTERIA MONOCYTOGENES, ESCHERICHIA COLI O157: H7 AND SALMONELLA TYPHIMURIUM DURING STORAGE ON BEEF SANITIZED WITH FUMARIC, ACETIC, AND LACTIC ACIDS 1', *Journal of food safety*, (15): 283-90.

———. 1996. 'Reduction of bacterial populations on vacuum-packaged ground beef patties with fumaric and lactic acids', *Journal of food protection*, (59): 1037-40.

Pohlman FW, MR Stivarius KS, McElyea ZB, Johnson MG, Johnson. 2002. 'The effects of ozone, chlorine dioxide, cetylpyridinium chloride and trisodium phosphate as multiple antimicrobial interventions on microbiological, instrumental color, and sensory color and odor characteristics of ground beef', *Meat Science*, (61): 307-13.

Popa Gabriela Loredana Mircea Ioan Papa. 2021. 'Salmonella spp. infection-a continuous threat worldwide', *Germs*, (11): 88.

Rahman SME, Jiyong Park Kyung Bin Song Naif A, AlHarbi DeogHwan Oh. 2012. 'Effects of slightly acidic low concentration electrolyzed water on microbiological, physicochemical, and sensory quality of fresh chicken breast meat', *Journal of food science*, (77): M35-M41.

Rahman SME, Jun Wang Deog-Hwan Oh. 2013. 'Synergistic effect of low concentration electrolyzed water and calcium lactate to ensure microbial safety, shelf life and sensory quality of fresh pork', *Food Control*, (30): 176-83.

Sheng Xiaowei Dengqun Shu Xiajun Tang Yitian Zang. 2018. 'Effects of slightly acidic electrolyzed water on the microbial quality and shelf life extension of beef during refrigeration', *Food Science & Nutrition*, (6): 1975-81.

Shi, Yige Dandan Pu, Xuewei Zhou Yuyu Zhang. 2022. 'Recent progress in the study of taste characteristics and the nutrition and health properties of organic acids in foods', *Foods*, (11): 3408.

Sun, Junzheng Xuanjing Jiang Yihui Chen Mengshi Lin, Jinyan Tang, Qin Lin, Ling Fang, Meiling Li, Yen-Con Hung, and Hetong Lin. 2022. 'Recent trends and applications of electrolyzed oxidizing water in fresh foodstuff preservation and safety control', *Food Chemistry*, (369): 130873.

Suzuki Tetsuya Jun Itakura Masumi Watanabe Mari Ohta, Yuri Sato Yuko Yamaya. 2002. 'Inactivation of Staphylococcal enterotoxin-A with an electrolyzed anodic solution', *Journal of Agricultural and Food Chemistry*, (50): 230-34.

Tango CN, AR, Mansur GH, Kim DH, Oh. 2014. 'Synergetic effect of combined fumaric acid and slightly acidic electrolysed water on the inactivation of foodborne pathogens and extending the shelf life of fresh beef', *Journal of applied Microbiology*, (117): 1709-20.

Turner Nicholas A, Batu K, Sharma-Kuinkel Stacey A, Maskarinec Emily M, Eichenberger Pratik P, Shah Manuela Carugati Thomas L, Holland Vance G, Fowler Jr. 2019. 'Methicillin-resistant Staphylococcus aureus: an overview of basic and clinical research', *Nature Reviews Microbiology*, (17): 203-18.

Vila-Clarà Gil Anna Vila-Martí Laia Vergés-Canet Miriam Torres-Moreno. 2024. 'Article Review: Role and Functionality of Ingredients in Plant-Based Meat Analogue Burgers'.

Wang Li, Lei Shi, MJ Alam Yuhuan Geng and Lin Li. 2008. 'Specific and rapid detection of foodborne Salmonella by loop-mediated isothermal amplification method', *Food Research International*, (41): 69-74.

Yoon KiBok, Byung-Joon Song MiYeong Shin HyunCheol Lim Yeon-Hee Yoon Doo-Young Jeon, Hoon Ha, Soo-In Yang, and Jung-Beom Kim. 2017. 'Antibiotic resistance patterns and serotypes of Salmonella spp. isolated at Jeollanam-do in Korea', *Osong public health and research perspectives*, (8): 211.

Zhao, Lingyu Imran Mahmood Khan Bin Wang Lin Yue, Yin Zhang Zhouping Wang Wenshui Xia. 2022. 'Synthesis and antibacterial properties of new monomethyl fumaric acidmodified chitosan oligosaccharide derivatives', *International Journal of Food Science & Technology*, (57): 2872-78.