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Review Article

Beneficial Application of Electrolyzed Water in Food Industry

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ABSTRACT

Electrolyzed water (EW) is a novel technology that has arisen in recent years with potential applications in foods, mostly in microbiological features, with variations in application modalities, dipping the item in solution, where duration may be varied, and being applied in the form of spray. Additionally, EW is a potent sanitizing tool that has received a lot of attention in the food business worldwide.

Due to the EW properties, its activity on microorganisms is still being explored for mechanism elucidation and potential harm, as well as its influence on intrinsic food features like as color and oxidation. This unconventional or 'green' technology aims to demonstrate the microbiological contamination control of food while exclude or not rely on the use of chemical disinfectants as chlorinated water which may result in producing little chemical/toxic residues.

This review covered the use of EW in animal-derived foods, emphasizing its safety level, shelf life, and processing.

INTRODUCTION

Today's environmental scenario emphasizes the prudent use of natural resources. Emerging technologies feature properties that reduce energy, chemicals and water use. The idea behind this technology is to dispose the use of chemical sanitizers to reduce its harmful residues while still having the potential for many various applications, especially in the food business. The quest for alternatives to standard technology aims to improve the applied methods for control of food microbiology & food technology, physicochemical properties, and food quality. Green chemistry is one or more of the principles of electrolyzed water technology **(Proctor. A, 2011).**

In addition, Foodborne illness has become a major public health concern across the world. According to the Centre for Disease Control and Prevention (CDC), more than 250 foodborne illnesses have been discovered thus far, resulting in 48 million people becoming ill in the United States each year. More precisely, around 128 000 people are hospitalized each year, and 3000 people die, inflicting patients

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pain and a costly burden on society. According to the CDC 2016 annual report, norovirus caused the majority of foodborne infections, followed by *Salmonella* and Shiga toxin-producing *Escherichia coli* **(López-Gálvez. F *et al.*, 2021)**. As a result, cleaning and sanitization are two of the most important procedures in ensuring food safety throughout food processing, as monitored by the Hazard Analysis and Critical Control Point (HACCP) system.

Electrolyzed water (EW) may serve as an innovation with many uses in the food industry since it is adaptable, easily produced, and requires little alterations in locations where water is already utilized **(Athayde, D. R. *et al.*, 2018)**. EW, as one of the most intriguing sterilization agents for microbial control in the food industry in the past few years, can be generated from diluted NaCl solution and displays strong broad-spectrum bactericidal performance owing to the synergistic contribution of available hypochlorous acid with chemical formula (HOCl) and molecular formula (HClO), hypochlorite ions (ClO^-), pH, and oxidation-reduction potential (ORP) **(Zhao, L. *et al.*, 2021).**

The key benefits of EW are the utilization of brine in production and the potential of local acquisition **(Al-Haq, M.I. *et al.*, 2005 and Huang, Y.R. *et al.*, 2008)**. Other benefits include the safety of EW at neutral or basic pH, when HOCl or OCl- are present, which have strong action on bacteria and a limited evaporation capacity **(White, G. C., 2010)**. Another advantage is the wide range of uses, such as spray, ice, and food dipping in EW. Also, it is produced very fast and simple, with cheap manufacturing costs, avoiding the transit, storage, and environmental risks associated with chemical goods. The latest innovations of food industry designed to relies on the use of such new and novel application option **(Athayde, D. R. *et al.*, 2018)**. Because of its significant bactericidal effects on many spoilage and pathogenic bacteria, including as *Salmonella* and *Escherichia coli* **(Gómez-López ,V.M. *et al.*, 2015 and Han, D. *et al*, 2018)**؛

EW has been frequently favor to be as an alternative of chemical disinfectant for slaughter houses. Actually, electrolyzed water comes in two varieties: acid electrolyzed water (AEW) and slightly acid electrolyzed water (SAcEW). The ease of manufacture, ease of industrial and agricultural use, efficient antibacterial activity, and cost-effectiveness of EW have all boosted its use **(Han, D. *et al*, 2018 and Gil, M.I. *et al.*, 2015)**؛

Therefore, the objectives of this review were to focus on the fundamentals of EW in the food industry, including its composition, benefits and drawbacks, processes, applications, and other certain trends.

FOOD CONTAMINATION

Microbial contamination is a frequent public issue in the food business since it can lower the shelf life and increase the danger of fresh meat and meat products being contaminated. Reduced microbial contamination during animal slaughter is critical for both producers and customers to prevent economic losses and health risks **(Patsias, A. *et al.*, 2006 and Petrou, S. *et al*, 2012)**. Because of their antimicrobial efficacy, convenience, and low cost, chlorine-based decontamination disinfectants such as sodium hypochlorite (NaClO) and chlorine dioxide (ClO_2) are the most commonly used interventions in animal slaughter plants **(Ban, G.H. & Kang, D.H., 2016; Duan, D. *et al.*, 2017 and Visvalingam, J. & Holley, R.A., 2018).** However, past research has cautioned consumers about chlorine's low efficiency for microbe reduction on meat and meat-contact surfaces **(Cai, L. *et al.*, 2018; Park, S.H & Kang, D.H., 2018 and Killinger, K.M. *et al.*, 2010)**.

Furthermore, toxic chlorination by-products, primarily chloroform, trihalomethanes, and halo acetic acids, have been detected in cheese and beverages as a result of disinfectants employed in the industry to clean and sanitize every contact surfaces and processing tools, as well as its formation during the food manufacturing process as a result of reactions between chlorine residuals and precursors that exist in foods (carbohydrates, lipids, and proteins) **(Cardador, M.J., 2016).**

It was additionally established that sodium hypochlorite, when employed as a disinfectant, may create chloroform when it reacts with organic molecules **(Waters, B.W. & Hung, Y., 2014)**. According to World Health Organization (WHO) warnings, the possible consumers' health danger of chlorinated by-products including increase cancer risk, spontaneous abortions, and birth deformities. Due to the limitations of typical chlorine-based disinfectants, the search for alternative disinfectants for meat and poultry decontamination is continuing **(Wang, H. *et al.,* 2019)**.

Consequently, EW has been employed to improve the quality and safety of animal-derived meals during several processing phases. In poultry business, for example, EW serves to disinfect processing plant water, lowering the danger of cross-contamination **(Melo, E.F. *et al.,* 2019)**. It can also be used to sanitize equipment and surfaces in meat processing plants **(Rebezov, M. *et al.,* 2022)**. These EW techniques can assist to lower the danger of contamination in the food manufacturing process.

The use of EW successfully decreases microbial contamination and has significantly contributed to the delayed rotting of meat. It is a non-toxic liquid that spells doom only for harmful germs, not natural human body processes. Empowered Water is a gentle substance that doesn't have any harmful elements. It can be used as sanitizer without worrying about toxic chemical traces. However, there are several problems about using electrolyzed water in the meat business, such as the stability of accessible chlorine under varied storage conditions, corrosion resistance, and residual chlorate **(Wang, H. *et al.,* 2019)**.

ELECTROLYZED WATER (EW) MECHANISM

The electrolysis of water and EW making process occurs when a sodium chloride brine (or other salt with chlorine) pass through an electrolysis cell with two poles: anode (+) and cathode (-), with or without membrane. Systems with membrane division can result in two types of water: acidic electrolyzed water (AEW) at anode side and basic (alkaline) electrolyzed water (BEW) at cathode side **(Huang, Y.R. *et al.,* 2008 and Cui, X., 2009)**. The mains products in anode are chlorine gas (Cl2) dissolved, hypochlorous acid (HOCl) and hydrochloric acid (HCl), and at the cathode is sodium hydroxide (NaOH) and H2 dissolved. Anode produces water with sanitizer characteristics and cathode produces water with cleaning properties, mainly because Cl2 and HOCl) and NaOH, respectively **(Athayde, D.R. *et al.,* 2018)**.

When an electrical current is sent through a solution of water and salt, hypochlorous acid (HOCl) and sodium hydroxide (NaOH) are formed. The active component responsible for EW's antibacterial effects is HOCl. A diluted salt solution is fed through an electrolytic cell with a membrane divider between the two electrodes, and AEW is produced in the anode at low pH, high ORP, and high accessible chlorine concentration (ACC). SAcEW is kind of electrolyzed water that has a greater pH, lower ORP, and lesser ACC than AEW. It is produced by running diluted NaCl or HCl solutions through an electrolytic cell with no membrane between the two electrodes **(Gil, M.I. *et al.*, 2015 and Rahman, S.M.E. *et al.,* 2010)**

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EW APPLICATIONS IN FOOD

Electrolyzed water has been increasingly employed in the field of food science and technology over the past few decades because of its environmental friendliness, low cost, and ease of application. The look of EW was initially employed as a sanitizer and cleaning agent. EW has demonstrated considerable application potential in food sanitation by eliminating common pathogens such as viruses, bacteria, and fungus in a very short amount of time. The use of EW in food preservation is mostly concerned with the microbial management of poultry, beef, seafood, fruits and vegetables **(Rahman, S.M.E. *et al.,* 2016)**.

Electrolyzed water is used in a variety of foods, usually in conjunction with the action of bacteria. Some AEW characteristics in *Vibrio parahemolyticus* and *Listeria monocytogenes* were examined in prawn storage at various temperatures **(Xie, J. *et al.,* 2012)**. Other research using *Vibrio parahemolyticus* was conducted in shrimps **(Wang, J.J. *et al.,* 2014 and Wang, J.J. *et al.,* 2014)**, while **Quan, Y. *et al.*, 2010** evaluated SAcEW impact in *Vibrio vulnificus* and compared the effects of EW to sodium hypochlorite. The influence of EW on *E. coli* and *Salmonella* spp. in frozen shrimp was investigated, as well as the influence on quality **(Loi-Braden, M.H. *et al.,* 2005)**. AEW in ice form was tested on shrimp quality preservation in the dark settings **(Lin, T. *et al.,* 2013)**, where AEW ice is a good inhibitor of polyphenol oxidase enzyme, which causes melanosis and loss in shrimp acceptability **(Wang, J.J. *et al.,* 2014)**.

Numerous investigations have demonstrated that EW may successfully eliminate harmful microorganisms in animal-derived foods. For example, **Liao, X. *et al.*, 2020** discovered that washing chicken with 50 ppm EW for 5 minutes greatly decreased *Salmonella* and *Campylobacter* populations. In a similar way, **Ananda Baskaran, S. *et al.,* 2012** concluded that spraying 50 ppm EW on cattle carcasses decreased the counts of *E. coli* O157:H7 and *Listeria monocytogenes*. These findings imply that EW can be a valuable technique in lowering the risk of foodborne pathogens linked with meat and poultry products.

Electrolyzed water effectiveness was compared to 2% lactic acid and hypochlorite solutions in pork **(Mansur, A.R. *et al.*, 2015 and Brychcy, E. *et al.,* 2015)** and ready-to-eat meat with *Listeria monocytogenes*, *Salmonella typhimurium*, and *Campylobacter jejuni* **(Fabrizio, K.A. & Cutter, C.N., 2004)**. Moreover, EW impact was investigated by soaking fish, chicken, and beef surfaces in *E. coli, Salmonella*, and *Listeria monocytogenes* **(Al-Holy, M.A. & Rasco, B.A., 2015)**. In addition, dip treatment was used to study its effect on *Listeria monocytogenes* and Salmonella *typhimurium* in chicken breast flesh **(Rahman, S.M.E. *et al.,* 2012).** *Pseudomonas* spp. was also tested when SAEW was sprayed to fresh cut vegetables **(Pinto, L. *et al.,* 2015).**

The latest studies have demonstrated that EW treatment can not only control microorganisms in post-harvest fruits and vegetables, but also improve its quality by delaying senescence **(Aday, M.S., 2016)**, controlling diseases **(Hussien, A. *et al.,* 2018)** and alleviating chilling injury **(Shi, F. *et al.,* 2020)**. Furthermore, some research has indicated that EW treatment can eliminate pesticide residues in fresh fruits and vegetables **(Qi, .H *et al.,* 2018)**. As a result, EW treatment appears to be a very promising approach of maintaining post-harvest fruits and vegetables **(Athayde, D.R. *et al.,* 2018)**.

EW AND SHELF-LIFE

Previous research has shown that using AEW and SAcEW in a laboratory environment or large-scale chicken slaughter factories may not only lower the initial microbial load but also increase the shelf life of chicken carcasses **(Duan, D. *et al.,* 2017 and Wang, H. *et al.,* 2018).** EW has also been proven to extend the shelf life of animal-derived foods by suppressing rotting germs **(Liao, X. *et al.*, 2020)**, for example, discovered that washing chicken with EW increased its shelf life by up to 5 days. Similarly, **Ananda Baskaran S. *et al.*, 2012** showed that spraying of beef carcasses with EW, increased the shelf life by up to 10 days. These outcomes indicated that EW can be utilized to increase the shelf life of meat and poultry products.

EW STORAGE

Whereas it is preferable to utilize electrolyzed water immediately after preparation to maximize its bactericidal effects, it is occasionally necessary to retain the water for a length of time **(Nagamatsu, Y. *et al.,* 2002).** The purification effects of EW are directly connected to its ACC stability during storage circumstances and in the presence of organic contaminants **(Okano, T. *et al.,* 2022 and Ding, T. *et al.,* 2016)**. Many research suggested that EW without organic compounds is the best treatment condition **(Chen, Y. *et al.,* 2017)**. Yet, this is an ideal circumstance since organic chemicals are abundant in meat slaughtering settings.

Despite the fact that fresh water is constantly delivered into the chiller tank in the chicken slaughter line, a rise in different organic compounds from carcasses can be plainly seen. The presence of organic materials could lead to the degradation and undesired consumption of ACC, directly resulting in an ACC decrease and weakening decontamination effectiveness. Therefore, it is of great significance to evaluate ACC changes during different storage conditions and in the presence of organic materials **(Wang, H. *et al.,* 2019 and Ayebah, B. & Humg, Y., 2005)**

EW DRAWBACKS

Little is known about the principal problems of electrolyzed water in practical applications, such as the stability of available chlorine under varied storage conditions, corrosion resistance, and residual chlorate **(Yan, P. *et al.,* 2021)**. Another drawback, due to the presence of organic debris (protein & lipids), which can induce a reduction in EW activity **(Cressey, P. *et al.,* 2008).** Also may cause a side effect in infants exposed to high level of chlorate or its toxic byproducts

Regular assessment of electrolyzed water's corrosiveness on metals is crucial. The use of chlorine-based disinfectants in conjunction with electrolyzed water also contributes to chlorate contamination in food **(Ayebah, B. & Hung, Y., 2005; Han, Q. *et al.,* 2017; Li, F. *et al.,* 2022 and Zhang, B. *et al.,* 2023)**. The WHO suggests 0.7 mg/L as a guideline for chlorate concentrations in potable water, and the European Food Safety Authority (EFSA) published an opinion on the chronic and acute public health risks of dietary exposure to chlorate, resulting in a tolerable daily intake of 0.003 mg chlorate/kg body weight and an acute reference dose of 0.036 mg/kg body weight **(WHO, 2017 and EFSA, 2015)**. Accordingly, monitoring the quantities of residual chlorate in electrolyzed water applications is thus a critical concern.

CONCLUSION

Based on the present review, EW has demonstrated encouraging outcomes in enhancing the safety and shelf life of animal-derived foods. It can be used in a variety of processing processes to mitigate microbial contamination and increase the shelf life of meat and poultry products. More studies are needed, however, to assess the long-term effects of EW on food quality and safety, as well as the possible environmental repercussions of its usage.

As a whole, EW looks to be a valuable tool in the food sector, but its application should be closely controlled and regulated to ensure food safety and sustainability. More research is needed on this technology and its potential uses in the food sector, as well as its features and processes.

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REFERENCES

Aday MS (2016). Application of electrolyzed water for improving postharvest quality of mushroom. LWT - Food Sci Technol 68:44–51. https://doi.org/https://doi.org/10.1016/j.lwt.2015.12.014

Al-Haq MI, Sugiyama, J, Isobe S (2005). Applications of electrolyzed water in agriculture and food industries. Food Sci Technol Res 11:135–150

Al-Holy MA, Rasco BA (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 54:317–321. https://doi.org/https://doi.org/10.1016/j.foodcont.2015.02.017

Ananda Baskaran S, Upadhyay A, Upadhyaya I (2012). Efficacy of octenidine hydrochloride for reducing Escherichia coli O157: H7, Salmonella spp., and Listeria monocytogenes on cattle hides. Appl Environ Microbiol 78:4538–4541. https://doi.org/10.1128/AEM.00259-12

Athayde DR, Flores DR, Silva JS, Silva MS, Genro AL, Wagner R, Campagnol PC, Menezes CR CA (2018). Characteristics and use of electrolyzed water in food industries. Int Food Res Journal 25:

Ayebah B and Hung Y (2005). Electrolyzed water and its corrosiveness on various surface materials commonly found in food processing facilities. J Food Process Eng 28:247–264

Ban GH and Kang DH (2016). Effect of sanitizer combined with steam heating on the inactivation of foodborne pathogens in a biofilm on stainless steel. Food Microbiol 55:47–54. https://doi.org/10.1016/j.fm.2015.11.003

Brychcy E, Magdalena M, Drozdzewski P, Ulbin Figlewicz N, Jarmoluk A (2015). Low_concentrated acidic eletrolysed water treatment of pork: inactivation of surface microbiota and changes in product quality. Int J Food Sci Technol 50:2340–2350.

Cai L, Wang H, Liang L (2018). Response of formed-biofilm of Enterobacter cloacae, Klebsiella oxytoca, and Citrobacter freundii to chlorite-based disinfectants. J Food Sci 83:1326–1332. https://doi.org/10.1111/1750-3841.14149

Cardador MJ, Gallego M, Cabezas L, Fernández-Salguero J (2016). Detection of regulated disinfection by-products in cheeses. Food Chem 204:306–313

Chen Y, Hung YC, Chen M, Lin H (2017). Effects of acidic electrolyzed oxidizing water on retarding cell wall degradation and delaying softening of blueberries during postharvest storage. Lwt 84:650–657. https://doi.org/10.1016/j.lwt.2017.06.011

Cressey P, Nokes C, Lake R (2008). Chlorinated compounds formed during chlorine wash of chicken meat. New Zeal Inst Environ Sci Res Ltd. Christchurch Sci Centre

Cui X, Shang Y, Shi Z (2009). Physicochemical properties and bactericidal efficiency of neutral and acidic electrolyzed water under different storage conditions. J Food Eng 91:582–586. https://doi.org/https://doi.org/10.1016/j.jfoodeng.2008.10.006

Ding T, Xuan XT, Li J (2016) Disinfection efficacy and mechanism of slightly acidic electrolyzed water on Staphylococcus aureus in pure culture. Food Control 60:505–510. https://doi.org/10.1016/j.foodcont.2015.08.037.

Duan D, Wang H, Xue S (2017). Application of disinfectant sprays after chilling to reduce the initial microbial load and extend the shelf-life of chilled chicken carcasses. Food Control 75:70–77. https://doi.org/10.1016/j.foodcont.2016.12.017

EFSA Panel on Contaminants in the Food Chain (2015). Risks for public health related to the presence of chlorate in food. EFSA J 13:4135. https://doi.org/https://doi.org/10.2903/j.efsa.2015.4135

Fabrizio KA, Cutter CN (2004). Comparison of electrolyzed oxidizing water with other antimicrobial interventions to reduce pathogens on fresh pork. Meat Sci 68:463–468. https://doi.org/https://doi.org/10.1016/j.meatsci.2004.04.013

Gil MI, Gómez-López VM, Hung Y-C, Allende A (2015). Potential of electrolyzed water as an alternative disinfectant agent in the fresh-cut industry. Food Bioprocess Technol 8:1336–1348.

Gómez-López VM, Gil MI, Pupunat L, Allende A (2015). Cross-contamination of Escherichia coli O157: H7 is inhibited by electrolyzed water combined with salt under dynamic conditions of increasing organic matter. Food Microbiol 46:471–478. https://doi.org/10.1016/j.fm.2014.08.024

Han D, Hung Y-C, Wang L (2018). Evaluation of the antimicrobial efficacy of neutral electrolyzed water on pork products and the formation of viable but nonculturable (VBNC) pathogens. Food Microbiol 73:227–236. https://doi.org/10.1016/j.fm.2018.01.023

Han Q, Song X, Zhang Z (2017). Removal of foodborne pathogen biofilms by acidic electrolyzed water. Front Microbiol 8:988.

Huang YR, Hung, YC, Hsu, SY, Huang, YW, Hwang DF (2008). Application of electrolyzed water in the food industry. Food Control 19:329–345. https://doi.org/10.1016/j.foodcont.2007.08.012

Hussien A, Ahmed Y, Al-Essawy A-H, Youssef K (2018) Evaluation of different salt-amended electrolysed water to control postharvest moulds of citrus. Trop Plant Pathol 43:10–20. https://doi.org/10.1007/s40858-017-0179-8

Killinger KM, Kannan A, Bary AI, Cogger CG (2010). Validation of a 2 percent lactic acid antimicrobial rinse for mobile poultry slaughter operations. J Food Prot 73:2079–2083. https://doi.org/10.4315/0362-028x-73.11.2079.

Li F, Zhong Q, Kong B (2022). Synergistic effect and disinfection mechanism of combined treatment with ultrasound and slightly acidic electrolyzed water and associated preservation of mirror carp (Cyprinus carpio L.) during refrigeration storage. Food Chem 386:132858. https://doi.org/10.1016/j.foodchem.2022.132858

Liao X, Xiang Q, Cullen PJ (2020). Plasma-activated water (PAW) and slightly acidic electrolyzed water (SAEW) as beef thawing media for enhancing microbiological safety. Lwt 117:108649. https://doi.org/10.1016/j.lwt.2019.108649

Lin T, Wang JJ, Li JB, Liao C, Pan YJ, Zhao Y (2013). Use of Acidic electrolyzed water ice for preserving the quality of shrimp. J Agric Food Chem 61:8695–8702. https://doi.org/10.1021/jf4019933

Loi-Braden MH, Huang TS, Kim JH, Wei C, Weese J (2005). Use of electrolyzed oxidizing water for quality improvement of frozen shrimp. J Food Sci 70:M310–M315. https://doi.org/10.1111/j.1365-2621.2005.tb11453.x

López-Gálvez F, Allende A, Gil MI (2021). Recent progress on the management of the industrial washing of fresh produce with a focus on microbiological risks. Curr Opin Food Sci 38:46–51. https://doi.org/https://doi.org/10.1016/j.cofs.2020.10.026

Mansur AR, Tango CN, Kim G-H, Oh D-H (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 47:277–284. https://doi.org/https://doi.org/10.1016/j.foodcont.2014.07.019

Melo EF, Clímaco WLS, Triginelli M V (2019). An evaluation of alternative methods for sanitizing hatching eggs. Poult Sci 98:2466–2473. https://doi.org/https://doi.org/10.3382/ps/pez022

Nagamatsu Y, Chen K-K, Tajima K (2002). Durability of bactericidal activity in electrolyzed neutral water by storage. Dent Mater J 21:93–104

Okano T, Sakamoto T, Ishikawa S (2022). Disinfection of otorhinolaryngological endoscopes with electrolyzed acid water: A cross-sectional and multicenter study. PLoS One 17:e0275488. https://doi.org/10.1371/journal.pone.0275488

Park SH and Kang DH (2018). Effect of temperature on chlorine dioxide inactivation of Escherichia coli O157: H7, Salmonella typhimurium, and Listeria monocytogenes on spinach, tomatoes, stainless steel, and glass surfaces. Int J Food Microbiol 275:39–45. https://doi.org/10.1016/j.ijfoodmicro.2018.03.015

Patsias A, Chouliara I, Badeka A (2006). Shelf-life of a chilled precooked chicken product stored in air and under modified atmospheres: microbiological, chemical, sensory attributes. Food Microbiol 23:423–429. https://doi.org/10.1016/j.fm.2005.08.004

Petrou S, Tsiraki M, Giatrakou V, Savvaidis IN (2012). Chitosan dipping or oregano oil treatments, singly or combined on modified atmosphere packaged chicken breast meat. Int J Food Microbiol 156:264–271. https://doi.org/10.1016/j.ijfoodmicro.2012.04.002

Pinto L, Ippolito A, Baruzzi F (2015). Control of spoiler Pseudomonas spp. on fresh cut vegetables by neutral electrolyzed water. Food Microbiol 50:102–108. https://doi.org/https://doi.org/10.1016/j.fm.2015.04.003

Proctor A (2011). Alternatives to conventional food processing, 2nd ed. Cambridge-UK: Royal Society.

Qi H, Huang Q, Hung YC (2018). Effectiveness of electrolyzed oxidizing water treatment in removing pesticide residues and its effect on produce quality. Food Chem 239:561–568. https://doi.org/https://doi.org/10.1016/j.foodchem.2017.06.144

Quan Y, Choi KD, Chung D, Shin IS (2010). Evaluation of bactericidal activity of weakly acidic electrolyzed water (WAEW) against Vibrio vulnificusand Vibrio parahaemolyticus. Int J Food Microbiol 136:255-260. https://doi.org/10.1016/j.ijfoodmicro.2009.11.005

Rahman SME, Ding T, Oh DH (2010). Effectiveness of low concentration electrolyzed water to inactivate foodborne pathogens under different environmental conditions. Int J Food Microbiol 139:147–153. https://doi.org/10.1016/j.ijfoodmicro.2010.03.020

Rahman SME, Park J, Song K Bin (2012). Effects of Slightly Acidic Low Concentration Electrolyzed Water on Microbiological, Physicochemical, and Sensory Quality of Fresh Chicken Breast Meat. J Food Sci 77:M35–M41. https://doi.org/https://doi.org/10.1111/j.1750-3841.2011.02454.x

Rahman SME, Khan I, Oh DH (2016). Electrolyzed Water as a Novel Sanitizer in the Food Industry: Current Trends and Future Perspectives. Compr Rev Food Sci Food Saf 15:471–490. https://doi.org/https://doi.org/10.1111/1541-4337.12200

Rebezov M, Saeed K, Khaliq A (2022). Application of electrolyzed water in the food industry: a review. Appl Sci 12:6639

Shi F, Li X, Meng H (2020). Reduction in chilling injury symptoms by hot electrolyzed functional water treatment may function by regulating ROS metabolism in Satsuma orange fruit. LWT 125: 109218. https://doi.org/https://doi.org/10.1016/j.lwt.2020.109218

Visvalingam J and Holley RA (2018). Evaluation of chlorine dioxide, acidified sodium chlorite and peroxyacetic acid for control of Escherichia coli O157: H7 in beef patties from treated beef trim. Food Res Int 103:295–300.

Wang H, Duan D, Wu Z. (2019). Primary concerns regarding the application of electrolyzed water in the meat industry. Food Control 95:50–56. https://doi.org/https://doi.org/10.1016/j.foodcont.2018.07.049

Wang H, Qi J, Duan D (2018). Combination of a novel designed spray cabinet and electrolyzed water to reduce microorganisms on chicken carcasses. Food Control 86:200–206. https://doi.org/https://doi.org/10.1016/j.foodcont.2017.11.027

Wang JJ, Lin T, Li BJ, Liao C, Pan, YJ, Zhao Y (2014). Effect of acidic electrolyzed water ice on quality of shrimp in dark condition. Food Control 35:207–212. https://doi.org/10.1016/j.foodcont.2013.07.005

Wang JJ, Sun WS, Jin MT, Liu HQ, Zhang W, Sun XH, Pan YJ, Zhao Y (2014). Fate of Vibrio parahaemolyticus on shrimp after acidic electrolyzed water treatment. Int J Food Microbiol 179:50-56. https://doi.org/10.1016/j.ijfoodmicro.2014.03.016

Wang JJ, Zhang ZH, Li JB, Pan YJ, Zhao Y (2014). Modeling Vibrio parahaemolyticus inactivation by acidic electrolyzed water on cooked shrimp using response surface methodology. Food Control 36:273–279. https://doi.org/10.1016/j.foodcont.2013.08.031

Waters BW and Hung Y (2014). The effect of organic loads on stability of various chlorine-based sanitisers. Int J food Sci

Technol 49:867–875

White GC (2010). Chemistry of Aqueous Chlorine. In: White's handbook of chlorination and alternative disinfectants., 5th ed. John Wiley and Sons., New Jersey.

WHO (World Health Organization) (2017). Guidelines for Drinking-water Quality: first addendum to the fourth edition.

Xie J, Sun XH, Pan YJ, Zhao Y (2012). Physicochemical properties and bactericidal activities of acidic electrolyzed water used or stored at different temperatures on shrimp. Food Res Int 47:331–336. https://doi.org/10.1016/j.foodres.2011.07.041

Yan P, Daliri EBM, Oh DH (2021). New clinical applications of electrolyzed water: a review. Microorganisms 9:136. https://doi.org/10.3390/microorganisms9010136

Zhang B, Zang Y, Mo Q (2023). Antibacterial activity and mechanism of slightly acidic electrolyzed water (SAEW) combined with ultraviolet light against Staphylococcus aureus. LWT 182:114746. https://doi.org/10.1016/j.lwt.2023.114746

Zhao L, Li S, Yang H (2021). Recent advances on research of electrolyzed water and its applications. Curr Opin Food Sci 41:180–188. https://doi.org/https://doi.org/10.1016/j.cofs.2021.03.004