JMBFS
Journal of Microbiology, Biotechnology and Food Sciences
International peer-reviewed scientific online journal
Published by Faculty of Biotechnology and Food Sciences

DECONTAMINATION EFFECT OF ELECTROLYZED WATER WASHING ON FRUITS AND VEGETABLES

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doi: 10.15414/jmbfs.2018.7.4.337-342

ARTICLE INFO

Received 10. 3. 2017
Revised 15. 11. 2017
Accepted 20. 12. 2017
Published 1. 2. 2018

Review

OPEN ACCESS

ABSTRACT

The use of electrolyzed water in the washing of fruits and vegetables is a promising alternative treatment to chlorine washing. Electrolyzed water washing, is safer, healthier, reduces cleaning times, and is ready to handle. In recent years, food poisoning outbreaks which are caused by bacteria with acid tolerance response in fruits and vegetables has increased. In addition, pathogen produce cases and outbreaks linked to fresh fruits and vegetables, such as cantaloupes, strawberries, fruit salads, spinach, lettuce, celery, and tomatoes has been encountered. Nowadays, the necessity of effective and healthy decontamination processes has gained more importance. The aim of this review is to offer a complete view about electrolyzed water, its classifications and applications. Decontamination results of extant literature of electrolyzed water were also presented. Also, the effects and results of electrolyzed water decontamination on the microbial counts of fresh fruits and vegetables compared with different sanitizing agents have been summarized.

Keywords: electrolyzed water, microbial reduction, fruits and vegetables

INTRODUCTION

There has been an increased concern about food safety regarding acute food borne diseases, infections, and intoxications. Despite the progresses in food science, food processing, and food hygiene, consumer awareness, food borne illnesses mediated by pathogenic microorganisms are still widespread and represent a significant threat to public health all over the world (**Huang *et al*., 2008; Issa-Zacharia *et al*., 2011**). In addition, food poisoning outbreaks, which are caused by bacteria with acid tolerance response in fruits and vegetables, has shown an increasing trend (**Weissinger *et al*., 2000; CDC, 2009**). Normally, the pH of fruits and vegetables is below the level that generally favors bacterial growth, although it is known that acid tolerance pathogens produce cases and outbreaks linked to fresh fruits and vegetables such as cantaloupes, strawberries, fruit salads, spinach, lettuce, celery, and tomatoes has increased. Over the past two decades, fruits and vegetables have repeatedly become a source of foodborne illnesses. The different pathogens most frequently linked to fruit and vegetable produce-related outbreaks generally include bacteria such as *Escherichia coli* O157: H7, *Salmonella* spp., and *Listeria* spp. which are a public health concern (**CDC, 2006; Nguyen-The, 2012; Olaimat & Holley, 2012**).
In order to obtain the desired microbiological quality in the food industry, the primary and the most important criterion is to achieve minimizing the number of microorganisms which contaminate the raw food material through different sources. This step should be done efficiently without decreasing the nutritional value of the food and damage to the environment. Decontamination of fresh fruits and vegetables is an important unsolved technological problem. The necessity for an effective wash water decontamination process in the raw material section of the fruit and vegetable industry is a very critical step. In fruit and vegetable cultivation, the possible contamination sources are seed, soil, irrigation water, animals, manure, and the use of sewage sludge. The washing methods can reduce the microbial load of the product. Thus, antimicrobial efficiency of the washing step could be thought as the assurance of the microbiological quality of the final product. Besides removing the microorganisms efficiently with washing, the selected method ought to be easily adapted to commercial lines, and should be simple and cheap (**Sivapalasingam *et al*., 2004; Ersus-Bilek & Turantas, 2013; Turantaş *et al*., 2015**). Several antimicrobial agents such as sodium hypochlorite, hydrogen peroxide, ethanol, organic acids, and ozone have been used as sanitizers in the food industry, besides their potential toxicity, they have proved incapable of completely removing or inactivating pathogens in food supplies. Currently, chlorine and chlorine derivatives regarded as cheap, and effective, are widely used sanitizers for reducing microbial contamination in the fresh-cut food industry. During the process, the chlorine solution loses its activity with exposure to air, light, metals, and its vapors may cause irritation to the skin and the respiratory tract (**Hostynek *et al*., 1990; Dychdala, 2001**). The by-products, trihalomethanes (THMs), chloroform, and chlorophenols carry a health risk because they are potentially mutagenic and have been classified by the US Environmental Protection Agency (EPA) as possible human carcinogens (**Ukuku & Fett, 2006; Ölmez & Kretzschmar, 2009; Cho *et al*., 2010**). Many regulations and guidelines have been applied to the food industry to stimulate the minimum activated chlorine concentration (ACC) in water streams (**Sharma & Demirci, 2003; Issa-Zacharia *et al*., 2010; Zhang *et al*., 2011**).
The electrolyzed oxidizing water (EOW), with low ACC is one of the potential alternatives to sodium hypochlorite usage with an environmentally friendly broad spectrum microbial decontamination in the food industry, so there is no need for the handling and storing of potentially dangerous chemicals (**Phuvasate & Su, 2010; Whangchai *et al*., 2010; Sapers, 2014**). EOW is created with the electrolysis of diluted sodium, potassium, and magnesium chloride solutions in an electrolysis chamber, having free chlorine in low concentration (low ACC) as a disinfection agent. EOW has the same or higher antimicrobial activity as a hypochlorite solution, even though it has less available chlorine than hypochlorite, it results greater effectiveness due to the continual production of available chlorine in the flow through the electrolysis chamber without hyperchlorination (**Koseki & Itoh, 2001; Kiura *et al*., 2002; Al-Haq & Gómez-López, 2012**). Especially, it has been reported that slightly acidic electrolyzed (SAEW) has some important advantages such as low ACC and high stability compare to the other antimicrobial agents. Because of these advantages, there has been growing interest in the use of SAEW as an alternative decontamination method. Hence, this review will provide an overview about EOW, its classifications and importance on treatments and decontamination effects of it as an alternative sanitizing agent to different chemicals especially chlorine in the fruit and vegetables decontamination processes. It defines the efficacy and properties of different kinds of EOW as a decontaminant and then focuses on the effect of the microbial counts in fruits and vegetables compared with different sanitizing agents.

PRODUCTION AND CLASSIFICATION OF ELECTROLYZED WATER

EOW is generated in a cell containing inert positively charged and negatively charged electrodes separated by a septum (it is called cationic membrane or diaphragm-**Morita *et al.*, 2000; Rivera, 2005**). The schematic illustration of acidic, basic (alkaline), and slightly acidic (low concentration) electrolyzed water generating equipment and the resulting compound during electrolysis are shown in Fig 1A and 1B, respectively. The current in the electrolyzing chamber and voltage between the electrodes are approximately set at 8~10 amperes and 9~10 volts, respectively. A saturated NaCl (or KCl/$MgCl_2$) solution and tap water are passed through this chamber. When a current is passed through this electrodialysis chamber, the solution is allowed to dissociate into the two streams of acidic and alkaline EOW which may be collected from their respective outlets:

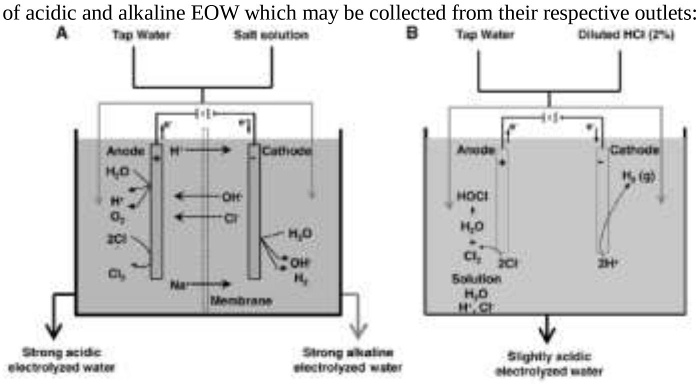

Figure 1 Schematic diagram of electrolyzed water and produced compounds during electrolysis (permission with **Issa-Zacharia *et al.*, 2010**)

Acidic electrolyzed water (AEW, AcEW or strong acidic electrolyzed water –StAEW-)

An electrolyzed acid solution from the anode stream (pH <2.7, oxidation-reduction potential-ORP, 950-1180 mV, high dissolved oxygen, and chlorine base reactants -also known as available chlorine content - ACC) at 10 to 90 mg/L and contains hypochlorous acid (HOCl), OCl^-, Cl_2, OH^-, and O_3, which has a strong antimicrobial effect (**Park *et al.*, 2001; Krasaekoopt & Bhandari, 2011; Teixeira & Rodriques, 2014**). For instance, AEW has been reported to have a strong bactericidal effect on most pathogenic bacteria such as *Escherichia coli* O157:H7, *Salmonella enteritidis*, *Salmonella typhimurium*, *Staphylococcus aureus*, *Listeria monocytogenes*, *Bacillus cereus*, *Enterobacter aerogenes*, and *Campylobacter jejuni (*2-6 log unit reductions) which are important for food safety (**Izumi, 1999; Al-Haq *et al.*, 2001; Kim *et al.*, 2001**). In addition to this strong antimicrobial effect, AEW has some disadvantages such as corrosion of the processing equipment and is dangerous to human health such as irritation of the personnel's skin and consequently limits its practical application (**Len *et al.*, 2002; Koseki *et al.*, 2003; Park *et al.*, 2004**). Primarily, it must be emphasized that the utilization of AEW has limited potential for long-term applications because of its strong acidity (pH<2.7), the antimicrobial effect of it can be rapidly decreased in time due to volatilization of dissolved Cl_2 gas and its negative impacts on human health and the environment. Despite not having any negative effect on the sensorial stability of products treated with AEW during refrigerated storage, some researchers mentioned that AEW can also have a deleterious effect such as loss of aroma, undesirable chemical burns, defects on the surface of leafy vegetables, browning of leaves, and electrolyte leakage caused by oxidation for some vegetables (**Wang *et al.*, 2004; Al-Haq *et al.*, 2005; Rahman *et al.*, 2010a**).

Neutral (NEW), near-neutral (NNEW), or slightly acidic electrolyzed water (SAEW)

Due to its neutral pH, the neutral electrolyzed water (NEW) does not exhibit as aggressively as AEW to the corrosion of processing equipment or irritation of hands, and is more stable for chlorine loss (**Abadias *et al.*, 2008**). NEW or SAEW (pH 5.0-6.5, ORP 800-900 mV, and ACC 10-30 mg/L) mainly contains biocidal reagents such as HOCl, ClO^-, HO_2, and O_2 because of advantages over that of AEW, it was mostly used as disinfectants for foods, processing equipments, utensils and food contact surfaces (**Al-Haq *et al.*, 2002; Kim *et al.*, 2003; Artés *et al.*, 2009**). SAEW has been an authorized food additive in Japan since 2002 because of its proven biological safety and antimicrobial effect even at low ACC of 10-30 mg/L (**Suzuki *et al.*, 2005; Issa-Zacharia *et al.*, 2011**). For instance, it was determined that NEW (or SAEW) was effective as a disinfectant for fresh-cut vegetables without causing discoloration, any detrimental effect of the tissue pH, surface colour, or general appearance of food products by different researchers (**Izumi, 1999; Tomás-Callejas *et al.*, 2011; Zhang *et al.*, 2011**). SAEW (NEW or low concentration EW) which has a stable and preferable microbiocidal effect than AEW, it may be related to the fact that dissolved chlorine does not decrease as much as AEW in time. The effective form of chlorine in SAEW is almost the HOCl having strong antimicrobial activity (**Yoshifumi, 2003; Huang *et al.*, 2008; Koide *et al.*, 2009**).

Basic electrolyzed water (BEW, ER water or AlEW)

An electrolyzed basic (alkaline) solution from the cathode stream (pH 10-11.5, ORP -800 to -900 mV, ACC 0 mg/L, and high dissolved hydrogen) which has a strong reducing potential is obtained (**Kitano *et al.*, 2003; Hsu *et al.*, 2004; Al-Haq *et al.*, 2005**). The BEW is classified as a cleaning compound and used in clean-in-place (CIP) applications or as the primary cleaner on food processing equipment (**Al-Haq *et al.*, 2005; Rivera, 2005; Pangloli *et al.*, 2009**).
The different researches which were published between 2003 and 2015, regarding physicochemical properties of neutral, near-neutral, and slightly electrolyzed waters applications in washing step of fruits and vegetables is summarized in Table 1.

DECONTAMINATION EFFECT OF ELECTROLYZED OXIDIZING WATER

The EOW term has also been classified as antimicrobial functional water and some scientists have used the different terminology for different types of electrolyzed water. Until today, different kinds of electrolyzed water (acidic, strong acidic, basic - alkaline, neutral, near neutral, or slightly acidic -low concentration) have been introduced as sanitizers and antimicrobial agents. In some studies of vegetable sanitization techniques which have been applied in fresh-cut produce, different types of electrolyzed water were used (**Gómez-López *et al.*, 2007; Afari *et al.*, 2016; Zhang *et al.*, 2016**). EOW is produced with the electrolysis of diluted sodium, magnesium or potassium chloride solutions in a generator chamber (Figure 1), but sodium chloride is generally used for food applications (**Koseki & Itoh, 2000; Al-Haq & Gómez-López, 2012; Gómez-López, 2012**). EOW has an antimicrobial activity against pathogens and spoilage microorganisms (**Vandekinderen *et al.*, 2009; Rahman *et al.*, 2010a; Graça *et al.*, 2011**) and has the same or more disinfectant ability as that of chlorine.
Although the antimicrobial mechanism of EOW has not been completely understood, there are some important factors such as electrochemically produced active chlorine derivatives (dissolved Cl_2 gas, HOCl, and OCl^-), reactive compounds and short-lived radicals (ozone, O^-, Cl^- and OH^-) and ORP and low pH (**Al-Haq *et al.*, 2005; Koide *et al.*, 2009; Zhang *et al.*, 2011**).

Table 1 Physicochemical properties of neutral, near-neutral, and slightly electrolyzed water which was used in published researches

Name or solution type	Abbreviation	pH	ORP (mV)	Available chlorine content (mg/L)	References
Neutral electrolyzed water	NEW [1]	8.13	803	430	
	NEW[2]	8.03	816	432	**Deza *et al.* (2003)**
	NEW[3]	7.99	795	465	
	NEW[4]	8.2	808	450	
Neutral electrolyzed water	NEW [1]	6.34	265.1	21	**Cui *et al.* (2009)**
	NEW[2]	6.51	512.6	25	
Neutral electrolyzed water	NEW	8.74	721	281	**Abadias *et al.* (2008)**
Neutral electrolyzed water	NEW[1]	8.42	767	101	**Graça *et al.* (2011)**
	NEW[2]	8.39	753	49	
Neutral electrolyzed water	NEW	7.0		410	**Tomás-Callejas *et al.* (2011)**
Neutral electrolyzed water	NEW	7.0	900	100	**Martínez-Hernández *et al.* (2013)**
Near-neutral electrolyzed water		6.5-6.7	800-900		**Guentzel *et al.* (2008)**
Slightly acidic electrolyzed water	SlAEW	5.0-6.5		10-30	**Koide *et al.* (2009)**

Slightly acidic electrolyzed water	SAEW[1] SAEW[2]	6.53 6.41	238.4 265.2	2 6	**Cao *et al.* (2009)**
Slightly acidic electrolyzed water	SAEW	5.8	948	21	**Issa-Zacharia *et al.* (2010)**
Slightly acidic electrolyzed water	LcEW	6.3	520	5	**Rahman *et al.* (2010a)**
Slightly acidic electrolyzed water	SAEW	5.98-6.48	817.5-893.8	20-120	**Zhang *et al.* (2011)**
Slightly acidic electrolyzed water	SAEW[1] SAEW[2]	6.19 5.95	860.25 873.85	19.61 29.42	**Liu *et al.* (2013)**
Electrochemically activated water	ECAW	7.0	864	100	**Yang *et al.* (2013)**
Near-neutral electrolyzed water	NEO	6.5	847	155	**Afari *et al.* (2016)**
Electrolyzed water	EO	2.5-6.5	836-1067	15-50	**Zhang *et al.* (2016)**
Low concentration electrolyzed water	LcEW	6.2	500-520	5	**Ding *et al.* (2011)**
Neutral electrolyzed water	NEW	6.5	750-900	500	**Rico *et al.* (2008)**
Neutral electrolyzed oxidizing water	NEW	8.3	-	45	**Gómez-López *et al.* (2007)**
Low concentration electrolyzed water	LcEW	6.2	500-520	5	**Rahman *et al.* (2010b)**
Neutralized electrolyzed oxidizing water	NEW	5.07	862.2	90.5	**Xiong *et al.* (2010)**

[1,2,3,4] Solution type used in the same research which has different physicochemical parameters

So, the antimicrobial mechanism of EOW has been attributed to these factors by most researchers. For instance, there are some studies that found a high correlation between the HOCl content of EOW and the antimicrobial effect of it (**Len *et al*., 2000; Al-Haq & Gómez-López, 2012**). On the other hand, **Huang *et al.* (2008)** concluded that the high ORP of EOW could cause the modification of metabolic fluxes and ATP production probably due to the change in the electron flow in the cells. In addition, **Demirci & Bialka (2011)** hypothesized that the low pH and high ORP sensitizes the membrane of the microorganisms allowing the active transfer of hypochlorous acid into the microbial cell. Similarly, these findings, **Liao *et al.* (2007)** reported that a theory for the inactivation of bacteria based on the high ORP of EOW causes damage to the cell membranes. Due to the several disadvantages of AEW, researches are focused on other types of electrolyzed water such as NEW, NNEW, or SAEW. In last years, EOW studies have focused on evaluating and comparing the disinfection efficiency of SAEW and other EOWs and antimicrobial agents such as NaOCl solutions. **Koide *et al.* (2009)** investigated the disinfection efficacy of SAEW (20 mg/L free chlorine, pH 6.1) in comparison to the NaOCl (150 mg/L free chlorine, pH 9.6) solutions on the total aerobic bacteria in fresh cabbage and the reductions were found as 1.6 and 1.5 log CFU/g, respectively, which are significantly higher than washing with tap water. When compared with the antimicrobial effects of SAEW, NaOCl, and control tap water, the number of mold and yeasts decreased to 1.3, 1.0, and 0.4, log CFU/g, respectively. The difference was found as being significantly important between the antimicrobial effect of NaOCl and SAEW ($P<0.05$). Similarly, many studies have also shown that SAEW may have an equivalent or higher microbiocidal effect than the NaOCl solution (**Cao et al., 2009; Kim *et al.*, 2009; Koide *et al*., 2009**). **Issa-Zacharia *et al.* (2010)** aimed to assess the sanitization potency of SAEW against pure cultures of *E. coli* and *S. aureus*, and then comparing the potency with the NaOCl solution. The surviving population of *E. coli* decreased with exposure time and only small differences were noted in the reduction rate of SAEW and NaOCl solution. Similarly, the surviving population of *S. aureus* decreased with the increase in exposure time and all tested solutions showed a similar sanitization effect to that of the observed when applied to *E. coli* (**Issa-Zacharia *et al.*, 2010**).

Rahman *et al.* (2010b) evaluated the efficacy of SAEW on lettuce leaves, under various treatment conditions for the inactivation of *L.monocytogenes, E. coli* O157:H7, *S. aureus*, and *S. typhimurium* with different dipping times (1, 3, 5, 7, and 10 min) and pH values of (2.5, 4.0, 5.0, 6.0, and 9.0) at room temperature (23±2 °C), and compared them with AEW (data not shown in table). The pH, ORP, and ACC of the treatment solutions used in this study are presented in Table 2. For 1 min dipping, the reduction in bacterial count through treatment with SAEW was about 5.20, 5.15, 4.90, and 6.21 log units CFU/ml for *L. monocytogenes*, *S. typhimurium*, *E. coli* O157:H7, and *S. aureus*, respectively, while the bacterial counts for samples treated with AEW were reduced by approximately 4.92, 4.82, 4.70, and 5.72 log units CFU/ml for same bacteria, respectively. The 1 min dipping time showed a higher log reduction in each bacterium than for those at 3, 5, 7, and 10 min. Thus, as dipping time increased, ACC reduced and the rate of log reduction decreased significantly ($P<0.05$). Results also indicated that SAEW containing 5 mg/L of activated chlorine was more effective than that of 50 mg/L AEW in reducing populations of bacterial strains, regardless of dipping time ($P<0.05$) (**Rahman *et al.*, 2010b**).

Table 2 Physicochemical properties of the treatment solutions (**Rahman *et al.*, 2010b**)

Treatment solutions	pH value	ORP(mV)	Available chlorine concentration (ACC- mg/L)
DW*	6.63±0.05	410±12	0.50±0.08
AEW*	2.60±0.10	1100±20	50±2.2
SAEW*	6.30±0.20	500±20	5±0.1

* DW: Distilled water; AEW: Acidic electrolyzed water; SAEW: Slightly acidic electrolyzed water

DECONTAMINATION EFFECT OF EOW IN FRUIT AND VEGETABLE WASHING

The researches carried out previously, regarding electrolyzed water usage for decontamination in the washing step for fruits and vegetables are summarized in Table 3. Most of the researches were published in the years between 2006 and 2016. In these studies, the effects with different types of EOW such as acidic, neutral, near neutral or slightly acidic with different pH, ACC, ORP and treatment times were generally evaluated in the washing treatments of lettuce, cabbage, spinach, leek, Chinese celery, bean, mushroom, broccoli, apples, and radish. Consequently, it can be said that the washing applications with electrolyzed water at different ACC, ORP, treatment times, and pH values are not interpreted in the same baseline for all experimental conditions because of the different foods, test microorganisms, applications, parameters of each experiment. Decontamination effect of different types of electrolyzed water is primarily depend on these different parameters which has been used in treatments.

There are some studies designed to investigate and compare the impact of electrolyzed water with other decontamination agents such as organic acids, sodium hypochlorite, gaseous chlorine dioxide, and peroxyacetic acid on the microbial inactivation of some fruits and vegetables (**Rahman *et al.*, 2010a; Ding *et al.*, 2011; Martínez-Hernández *et al.*, 2013**)

Table 3 Different electrolyzed water applications and microbial reductions in the washing decontamination process of fresh fruits and vegetables (summarized from published researches)

Food	Microorganism / Group	Reduction (log CFU/g)	Type of electrolyzed water/Treatment	pH	ACC (mg/L)	ORP (+mV)	References
Lettuce	Psychrotrophs Lactic acid bacteria Enterobacteriacae Mould and Yeast	1.9 1.2 1.3 0.11	Neutral/1 min	-----	3.6	----	**Ongeng *et al.* (2006)**
	Psychrotrophs Lactic acid bacteria Enterobacteriacae Mould and Yeast	3.30 2.60 1.90 0.30	Neutral/5 min				
	TVC*	0.21	Neutral/5min-centrifuge	8.3	45	------	

Cabbage	Lactic acid bacteria Psychrotrophs Yeasts	0.53 0.40 0.28					**Gómez-López *et al.* (2007)**
Iceberg lettuce	*E. coli* *Salmonella* *L. innocua* *E. coli* *Salmonella* *L. innocua*	1.60 1.50 1.30 1.80 1.30 1.40	Neutral/1-3 min -1 min rinsing with deionized water	8.6 8.55	52 89	722 733	**Abadias *et al.* (2008)**
Spinach leaves	*E. coli*	0.44 1.25 2.62	Neutral/10 min -rinsing with sterile water	6.5-6.7	4 20 50	800-900	**Guentzel *et al.* (2008)**
	S. aureus	0.52 2.04 3.47		6.5-6.7	4 20 50	800-900	
	S. Typhimurium	3.41 2.14 2.28		6.5-6.7	4 20 50	800-900	
	L. monocytogenes	3.77 2.94 ≥4.97		6.5-6.7	4 20 50	800-900	
	E. faecalis	2.9 2.86 ≥4.33		6.5-6.7	4 20 50	800-900	
Lettuce	*E. coli*	0.06 0.14 0.15	Neutral/10 min -rinsing with sterile water	6.5-6.7	4 20 50	800-900	
	S. aureus	0.03 1.43 2.79	Neutral/10 min -rinsing with sterile water	6.5-6.7	4 20 50	800-900	
	S. Typhimurium	0.83 1.41 2.90		6.5-6.7	4 20 50	800-900	
	L. monocytogenes	0.51 2.99 2.53		6.5-6.7	4 20 50	800-900	
	E. faecalis	1.66 2.80 2.60		6.5-6.7	4 20 50	800-900	
Iceberg lettuce	Mesophilic	2.20-2.40	Neutral/1 min -5 min drying with salad spinner	6.5	12- 120	750-900	**Rico *et al.* (2008)**
Leek	TVC	0.38 0.43	Neutral/1-5 min	7.5 7.8	4.5 30	-------	**Vandekinderen *et al.* (2009)**
Cabbage	TVC	1.50	Slightly acidic/10 min-rinsing with tap water /2 min	6.1	20	------	**Koide *et al.* (2009)**
Spinach	TVC Mould and Yeast *E. coli*	1.93 1.64 2.40	Slightly acidic/ 3 min	6.2	5	500-520	**Rahman *et al.* (2010a)**
Chinese celery, Lettuce, sprout	TVC	2.70 2.54 2.45	Slightly acidic/ 5 min	5.8	21	948	**Issa-Zacharia *et al.* (2011)**
Mung bean	*E. coli*	1.35[a] 2.56[b] 3.41[c] 4.37[d]	Slightly acidic/ 5 min	6.13-6.38	20 40 60 80	817-893	**Zhang *et al.* (2011)**
	S. enteriditis	1.31[a] 2.13[b] 3.28[c] 4.23[d]	Slightly acidic/ 5 min	5.98-6.27	20 40 60 80	837-889	
Minzuna baby leaves	Mesophilic	0.02 0.38	Neutral/ 2min -rinsing with tap water/1 min		40 70		**Tomás-Callejas *et al.* (2011)**
	Enterobacteria	1.00 1.30	Acidic/2 min - rinsing with tap water/1 min		40 70		
		1.20	Neutral/2 min - rinsing with tap water/1 min		100		
	Psychrophilic	1.89	Acidic/2 min- rinsing with tap water/1 min		40		
		1.77	Neutral/2 min- rinsing with tap water/1 min		40		
	Mould and Yeast	1 1	Acidic/2 min- rinsing with tap water/1 min		40 70		

		1 1 1 1	Neutral/2 min- rinsing with tap water/1 min		100 40 70 100		
Apple	*E. coli*	1.90^{a} 1.40^{b} 1.20^{bc} 0.99^{c}	Acidic/5 min Acidic/5 min Neutral/5 min Neutral/5 min (3 min rinsing with distilled water)	2.93 3.08 8.42 8.39	98 53 101 49	1128 1111 767 753	**Graça *et al.* (2011)**
Mushroom	TVC *E. coli* *L. monocytogenes* *S.* Typhimurium *B. cereus*	1.35 1.85 2.16 2.08 2.02	Slightly acidic/3 min	6.2	5	500-520	**Ding *et al.* (2011)**
	TVC *E. coli* *L. monocytogenes* *S.* Typhimurium *B. cereus*	1.40 1.78 2.08 2.04 1.95	Strong acidic/3 min	2.5	50	1100-1120	
Broccoli	Mesophilic Psychrophilic Mould and Yeast	1.90 1 ≥3.0	Neutral/2 min- rinsing with tap water/1 min	7	100	900	**Martínez-Hernández *et al.* (2013)**
Lettuce	*S.* Typhimurium DT 104 *E. coli* O157:H7	5.00 3.90	Near neutral/15 min	6.5	155	847	**Afari *et al.* (2016)**
Radish	TVC Mould and Yeast	2.50^{a} 2.20^{a} 2.20^{b} 2.20^{b}	Electrolyzed water/12 h soaking	2.5 6.5 2.5 6.5	25	——	**Zhang *et al.* (2016)**

*****Total Viable Count

The results of **Vandekinderen *et al.* (2009)** demonstrate that the reduction of the viable cells washed with different concentrations of some antimicrobials except peroxyacetic acid (250 mg/L) and chlorine dioxide gas (1.59 mg/L) was not significantly different. In addition, a reduction of approx. a 1.5 logarithmic unit was obtained for washing with a peroxyacetic acid (250 mg/L) and chlorine dioxide gas (1.59 mg/L) treatment, whereas, an 0.43 log unit was obtained after washing a fresh-cut leek with neutral electrolyzed water (30 mg/L ACC) for 1-5 min (Table 4).

Rahman *et al.* (2010a) investigated how to inactivate some microorganisms on spinach with washing with a slightly acidic (pH 6.2) and strong acidic (pH 2.54) EW and then compared it with other sanitizers such as aqueous ozone, citric acid, and sodium hypochlorite for 3 min at 23 °C (Table 5).

For all microorganisms, the similar pattern of microbial reduction was observed after slightly and strong acidic EW washing, no significant differences were determined among different washing treatments (P>0.05). The results of this research demonstrate that the slightly acidic EW washing (5mg/L ACC) can effectively reduce the number of *E. coli* and *L. monocytogenes* counts (2.4 and 2.8 log CFU/g reduction) on spinach when compared to the reductions of deionized water and sodium hypochlorite (100 mg/L ACC) washing with 0.80-0.95 and 2.0-2.2 log CFU/g reductions, respectively. As a result, slightly acidic EW was proposed as a promising sanitizer for washing vegetables in that study (**Rahman *et al.*, 2010a**).

Table 4 The efficiency of different disinfectants on the reduction of total viable count load of fresh cut leek (summarized from **Vandekinderen *et al.*, 2009**)

Washing Treatment-Parameters		**Reduction (log CFU/g)**
Tap water (Control)		0.05±0.25
Neutral electrolyzed water ACC	4.5 mg/L ACC	0.38±0.20
	30 mg/L ACC	0.43±0.79
NaOCl	20 mg/L ACC	0.84±0.42
	200 mg/L ACC	1.00±0.64
Peroxyacetic acid	80 mg/L	1.06±0.22
	250 mg/L	1.52±0.27
Chlorine dioxide gas	1.59 mg/L	1.48±0.48

The reduction values are given as means of log reduction ±SD

Table 5 The reduction values of different sanitizer washings for 3 min. on the total bacteria, mold and yeast, *E. coli*, and *L. monocytogenes* inoculated spinach samples (summarized from **Rahman *et al.*, 2010a**)

Washing Treatment	**Total bacteria (log CFU/g)**	**Mold and Yeast (log CFU/g)**	***E. coli* (log CFU/g)**	***L. monocytogenes* (log CFU/g)**
Deionized water	0.52^{a}	0.31^{a}	0.80^{a}	0.95^{a}
Slightly acidic EW (SAEW) (5 mg/L ACC)	1.93^{b}	1.64^{d}	2.40^{d}	2.80^{d}
Strong acidic EW (StEW) (50 mg/L ACC)	1.94^{b}	1.57^{d}	2.30^{d}	2.70^{d}
Aqueous ozone (5.3 mg O_3/L water)	1.07^{c}	0.88^{bc}	1.22^{bc}	1.40^{b}
Citric acid (1 %)	1.39^{cd}	1.05^{cd}	1.50^{c}	1.70^{b}
NaOCl (100 mg/L ACC)	1.61^{db}	1.38^{cd}	2.01^{d}	2.20^{c}

$^{a-d}$ Different subscripts show statistical significance (P<0.05) on the same column

In another study, **Ding *et al.* (2011)** investigated the effects of the same sanitizers which were used in Rahman's research (Rahman et al., 2010a) on the inactivation of same microbial groups except *S. typhimurium* and *B. cereus.* Samples treated with slightly acidic EW resulted in a greater log reduction than other sanitizers for all microorganisms, there was no statistically significant difference between the slightly acidic and strong acidic EW results (Table 6).

The reduction of the initial microbial load of the fresh-cut broccoli after singular and combined decontamination treatments are given in

Table 6 The reduction values of different sanitizers on *E. coli* O157:H7, *L. monocytogenes*, *S. typhimurium*, and *B. cereus* inoculated oyster mushrooms during a 3 min. immersion treatment at room temperature (summarized from **Ding *et al.*, 2011**)

Treatment	Total bacteria (log CFU/g)	Mold and Yeast (log CFU/g)	*E. coli* O157:H7 (log CFU/g)	*L. monocytogenes* (log CFU/g)	*S. typhimurium* (log CFU/g)	*B. cereus* (log CFU/g)
Deionized water	0.19^{d}	0.19^{cd}	0.39^{e}	0.62^{d}	0.66^{e}	0.57^{e}
Slightly acidic EW (pH:6.2 ORP 500-520 5 mg/L ACC)	1.35^{a}	1.08^{a}	1.85^{a}	2.16^{a}	2.08^{a}	2.02^{a}
Strong acidic EW (pH:2.5 ORP 1100-1120 50 mg/L ACC)	1.47^{a}	1.02^{ab}	1.78^{a}	2.08^{a}	2.04^{ab}	1.95^{ab}
Aqueous ozone (5 mg O_3/L water)	0.61^{c}	0.43^{c}	0.75^{d}	1.06^{c}	1.03^{d}	0.94^{d}
Citric acid (1 %)	0.9^{bc}	0.77^{b}	1.02^{c}	1.42^{b}	1.38^{c}	1.23^{c}
NaOCl (pH:9.8 100 mg/L ACC)	1.14^{ab}	0.88^{ab}	1.42^{b}	1.94^{a}	1.86^{b}	1.74^{b}

$^{a-e}$ Different subscripts show statistical significance (P<0.05) on the same column

Martínez-Hernández *et al.* (2013) evaluated the alternative decontamination processes of fresh-cut broccoli and applied the following treatments (Tab. 7);

- Sodium hypochlorite (NaOCl) washing (100 mg/L free chlorine/2 min at 5 °C),
- Neutral electrolyzed water washing (NEW) (100 mg/L ACC, 900 ORP, 2 min at 5 °C),
- Super atmospheric oxygen packaging (HO) (90 kPa O_2 partial pressure),
- UV-C treatment (6 kj UV-C/m^2),
- Combinations of these treatments at same parameters (NEW+UV-C; UV-C+HO; NEW+HO and NEW+UV-C+HO).

Although it is generally accepted, as a rule, that the application of combined treatments could have a synergistic effect leading to a better microbial reduction. **Martínez-Hernández *et al.* (2013)** determined that the logarithmic reductions of mesophilic, psychrophilic, and mold and yeast counts is not significantly different from each other which are singular and combined washing treatments. The highest microbial reduction of combined washing treatments on mesophilic bacteria count was also obtained with NEW+HO (1.9 log CFU/g reduction) when compared with other treatments.

Table 7 The effect of singular and combined decontamination treatments applied to fresh-cut broccoli on the reduction (log CFU/g) of mesophilic, psychrophilic bacteria, and mold and yeast counts (summarized from **Martínez-Hernández *et al.*, 2013**)

Washing treatment* (5°C- 2 min.)	Mesophilic bacteria (log CFU/g)	Psychrophilic bacteria (log CFU/g)	Mold and yeast counts (log CFU/g)
NaOCl (pH:6.5 100 mg/L ACC)	1.4^{a}	1.3^{a}	>3.1^{a}
UV-C Ultraviolet (6.0 kj UV-C/m^2),	1.2^{a}	0.8^{a}	0.2^{b}
Neutral EW (NEW) (pH:7 100mg/L ACC)	0.5^{a}	1.3^{a}	>3.1^{a}
HO*	1.0^{a}	<10^{a}	>3.1^{a}
UV-C+HO	1.2^{a}	0.8^{a}	0.2^{b}
NEW+HO	1.9^{b}	1.3^{a}	>3.1^{a}
NEW+UV-C	1.3^{a}	1.2^{a}	>3.1^{a}
NEW+UV-C+HO	1.3^{a}	1.2^{a}	>3.1^{a}

* HO: super atmospheric O_2 packaging (active MAP with an initial 90 kPa O_2 partial pressure)
$^{a-b}$ Different subscripts show statistical significance (P<0.05) on the same column

Table 8 The effect of electrolyzed water at different pH levels and the ACC at 22 ºC for a 12 hours soaking treatment of radish on the total aerobic bacteria, and mold and yeast counts (summarized from **Zhang *et al.*, 2016**)

Electrolyzed oxidizing water (EOW)	Total aerobic bacteria (log CFU/g)	Mold and yeast (log CFU/g)
Experiment 1		
25 mg/L ACC pH 2.5	2.46^{a}	2.21^{b}
25 mg/L ACC pH 6.5	2.17^{a}	2.27^{b}
Experiment 2		
15 mg/L ACC pH: 6.5	2.06^{a}	2.11^{a}
33 mg/L ACC pH: 6.5	2.40^{b}	2.58^{b}
40 mg/L ACC pH: 6.5	3.09^{c}	3.29^{c}

$^{a-c}$ Different subscripts show statistical significance (P<0.05) on the same column

Zhang *et al.* (2016) investigated the efficacy of EOW in reducing the total aerobic count and yeast and mold counts on radish samples during a 12 h soaking (Table 8). In the research, EOW with different ACC (15, 20, 28, 33, and 40 mg/L) and different pH levels (2.5, 3.5, 4.5, 5.5, and 6.5) were used to soak radish for 12 h and the reductions of microorganisms were determined. The results showed that the reduction of total aerobic bacteria and mold and yeast counts was not significantly different at different pH levels (2.5 - 6.5) of EOW at 25 mg/L ACC. Results also showed that the reduction of total aerobic bacteria and mold and yeast counts increased with the increasing ACC of EOW, while a significant difference was observed between 15, 33, and 40 mg/L ACC at a 6.5 pH level that was applied while soaking radish samples at 22ºC.

CONCLUSION

The decontamination effect of electrolyzed water is dependent on the organic load, pH, and ORP concentration in free oxidants and treatment times. As many researches have demonstrated that slightly acidic electrolyzed water with a near-neutral pH value exhibits an equivalent or higher bactericidal activity for some kinds of foods used in these researches compared to acidic electrolyzed water and sodium hypochlorite solution and could prevent cross-contamination of processing environments. It was also reported that slightly acidic electrolyzed water applied by itself showed 1.0-1.80 log unit microbial reduction on the number of TVC, mould and yeast counts, and some pathogens such as *E. coli*, *L. monocytogenes*, *S. typhimurium* and *B. cereus* in some vegetables. In light of this knowledge, further studies are required to determine the antimicrobial effect of slightly acidic electrolyzed water or other antimicrobial agents in order to compare the results for decontamination washing processes, and simulate typical commercial conditions which may then lead to the fruitful applications of it in the food industry. Application of electrolyzed water has been primarily focused on fruits and vegetables; its potential for surface decontamination of food products still requires further study and optimization. Especially, application parameters such as pH, ORP, temperature, treatment time, and active chlorine concentration, require optimization for washing minimally processed fruits and vegetables to increase the microbiocidal effect of electrolyzed water washing as a promising alternative technique.

REFERENCES

Abadias, M., Usall, J., Oliveira, M., Alegre, I., & Viñas, I. (2008). Efficacy of neutral electrolyzed water (NEW) for reducing microbial contamination on minimally-processed vegetables. *International Journal of Food Microbiology*, 123, 151-158. https://doi.org/10.1016/j.ijfoodmicro.2007.12.008

Afari, K.G., Hung, Y.C., King, C.H., & Hu, A. (2016). Reduction of *Escherichia coli* O157:H7 and *Salmonella Typhimurium* DT 104 on fresh produce using an automated washer with near neutral electrolyzed (NEO) water and ultrasound. *Food Control*, 63, 246-254. https://doi.org/10.1016/j.foodcont.2015.11.038

Al-Haq M.I, & Gómez-López, V.M. (2012). Electrolyzed oxidizing water. In: Gómez-López, V.M. (Ed.), *Decontamination of Fresh and Minimally Processed Produce*. USA:Wiley-Blackwell.
Al-Haq, M.I., Seo, Y., Oshita, S., & Kawagoe, Y. (2001). Fungicidal effectiveness of electrolyzed oxidizing water on postharvest brownrot of peach. *Hort Science*, 36(7), 1310–1314.
Al-Haq, M.I., Seo, Y., Oshita, S., Kawagoe, & Y. (2002). Disinfection effects of electrolyzed oxidizing water on suppressing fruit rot of pear caused by *Botryosphaeria berengeriana*. *Food Research International*, 35(7), 657–664. https://doi.org/10.1016/S0963-9969(01)00169-7
Al-Haq, M.I., Sugiyama, J., & Isobe, S. (2005). Application of electrolyzed water in agriculture and food industries, review. *Food Science and Technology Research*, 11(2), 135-150. http://doi.org/10.3136/fstr.11.135
Artés, F., Gómez, P., Aguayo, E., Escalona, V., & Artés-Hernández, F. (2009). Sustainable sanitation techniques for keeping quality and safety of fresh-cut plant commodities. *Postharvest Biology and Technology*, 51, 287–296. https://doi.org/10.1016/j.postharvbio.2008.10.003
Cao, W., Zhu, Z.W., Shi, Z.X., Wang, C.Y. & Li, B.M. (2009). Efficiency of sligtly acidic electrolyzed water for inactivation of *Salmonella enteritidis* and its contaminated shell eggs. *International Journal of Food Microbiology*, 130, 88-93. https://doi.org/10.1016/j.ijfoodmicro.2008.12.021
Centers for Disease Control and Prevention – CDC. (2006). Ongoing multistate outbreak of *Escherichia coli* serotype O157:H7 infections associated with consumption of fresh spinach United States, September 2006. *Morbidity and Mortality Weekly Report*, 55(38), 1045–1046.
Centers for Disease Control and Prevention – CDC. (2009). State Indicator Report on Fruits and Vegetables. https://www.cdc.gov/nutrition/downloads/StateIndicatorReport2009.pdf Accessed:25.01.17
Cho, S.D., Chang, M.S., Lee, Y.S., Ha, J.H., & Kim, G.H. (2010). Changes in the residual chlorine content of fresh-cut lettuce during storage. *Journal of the Korean Society for Applied Biological Chemistry*, 53(3), 337–341. https://doi.org/10.3839/jksabc.2010.052
Cui, X., Shang, Y., Shi, Z., Xin, H. & Cao, W. (2009). Physicochemical properties and bactericidal efficiency of neutral and acidic electrolyzed water under different storage conditions. *Journal of Food Engineering*, 91, 582-586. https://doi.org/10.1016/j.jfoodeng.2008.10.006
Demirci, A., & Bialka, K.I. (2011). Electrolyzed Oxidizing Water In: Zhang, H.Q., Barbosa-Cánovas, G.V., Balasubramaniam, V.M., Dunne, C. P., Farkas, D. F., Yuan, J. T. C. (Eds.). *Nonthermal processing technologies for food*. UK: Wiley-Blackwell, IFT Press.
Deza, M., Araujo, M., & Garrido, M.J. (2003). Inactivation of *Escherichia coli* O157:H7, *Salmonella enteritidis and Listeria monocytogenes* on the surface of tomatoes by neutral electrolyzed water. *Letters in Applied Microbiology*, 37, 482-487. https://doi.org/10.1046/j.1472-765X.2003.01433.x
Ding, T., Rahman, S.M.E., & Oh, D.H. (2011). Inhibitory effects of low concentration electrolyzed water and other sanitizers against foodborne pathogens on oyster mushroom. *Food Control*, 22, 318-322. https://doi.org/10.1016/j.foodcont.2010.07.030
Dychdala, G.R. (2001). Chlorine and chlorinated compounds. In: Block, S. S. (Ed.), *Disinfection, Sterilization and Preservation*. Lippincott: Williams and Wilkins.
Ersus Bilek, S., & Turantaş, F. (2013). Decontamination efficiency of high power ultrasound in the fruit and vegetable industry, a review. *International Journal of Food Microbiology*, 166, 155–162. https://doi.org/10.1016/j.ijfoodmicro.2013.06.028
Gómez-López, V.M. (2012). Progress in food preservation. In: Bhat, R., Alias, A.K., Paliyath, G. (Eds.), *Selected Techniques to Decontaminate Minimally Processed Vegetables*. UK: Wiley-Blackwell.
Gómez-López, V.M., Ragaert, P., Ryckeboer, J., Jeyachchandran, V., Debevere, J., & Devlieghere, F. (2007). Shelf-life, of minimally processed cabbage teated with neutral electrolyzed oxidising water and stored under equilibrium modified atmosphere. *International Journal of Food Microbiology*, 117, 91-98. https://doi.org/10.1016/j.ijfoodmicro.2007.02.016
Graça, A., Abadias, M., Salazar, M., & Nunes, C. (2011). The use of electrolyzed water as a disinfectant for minimally processed apples. *Postharvest Biology and Technology*, 61, 172-177. https://doi.org/10.1016/j.postharvbio.2011.04.001
Guentzel, J.L., Lam, K.L., Callan, M.A., Emmons, S.A., & Dunham, V.L. (2008). Reduction of bacteria on spinach, lettuce, and surfaces in food service areas using neutral electrolyzed oxidizing water. *Food Microbiology*, 25, 36-41. https://doi.org/10.1016/j.fm.2007.08.003
Hostynek, J.J., Wilhelm, K.P., Cua, A.B., & Maibach, H.I. (1990). Irritation factors of sodium hypochlorite solutions in human skin. *Article in Contact Dermatitis*, 23(5), 316-24. https://doi.org/10.1111/j.1600-0536.1990.tb05165.x
Hsu, S., Kim, C., Hung, Y., & Prussia, S.E. (2004). Effect of spraying on chemical properties and bactericidal efficacy of electrolyzed oxidizing water. International. *Journal of Food Science and Tecnology*, 39, 157-165. https://doi.org/10.1046/j.0950-5423.2003.00762.x
Huang,Y., R., Hung, Y.C., Hsu, S.Y., Huang, Y.W., & Hwang, D.F. (2008). Application of electrolyzed water in the food industry. *Food Control*, 19, 329–345. https://doi.org/10.1016/j.foodcont.2007.08.012
Issa-Zacharia, A., Kamitani, Miwa, N., Muhimbula, H., & Iwasaki, K. (2011). Application of slightly acidic electrolyzed water as a potential non-thermal food sanitizer for decontamination of fresh ready-to-eat vegetables and sprouts. *Food Control*, 22, 601-607. https://doi.org/10.1016/j.foodcont.2010.10.011
Issa-Zacharia, A., Kamitani, Y., Tiisekwa, A., Morita, K., & Iwasaki, K. (2010). In vitro inactivation of *Escherichia coli*, *Staphylococcus aureus* and *Salmonella* spp. using slightly acidic electrolyzed water. *Journal of Bioscience and Bioengineering*, 110(3), 308-313. https://doi.org/10.1016/j.jbiosc.2010.03.012
Izumi, H. (1999). Electrolyzed water as a disinfectant for fresh-cut vegetables. *Journal of Food Science*, 64, 536–539. http://doi.org/10.1111/j.1365-2621.1999.tb15079.x
Kim, C., Hung, Y.C., Brackett, R.E., & Frank, J.F. (2001). Inactivation of *Listeria monocytogenes* biofilms by electrolyzed oxidizing water. *Journal of Food Processing Preservation*, 25(2), 91–100. http://doi.org/10.1111/j.1745-4549.2001.tb00446.x
Kim, C., Hung, Y.C., Brackett, R.E., & Lin, C.S. (2003). Efficacy of electrolyzed oxidizing water in inactivating *Salmonella* on alfaalfa seeds and sprouts, *Journal of Food Protection*, 66, 208-214. https://doi.org/10.4315/0362-028X-66.2.208
Kim, Y.J., Kim, M.H., & Song, K.B. (2009). Efficacy of aqueous chlorine dioxide and fumaric acid for inactivating pre-existing microorganisms and *Escherichia coli* O157:H7, *Salmonella typhimurium* and *Listeria monocytogenes* on broccoli sprouts. *Food Control*, 20, 1002-1005. https://doi.org/10.1016/j.foodcont.2008.12.005
Kitano, J., Kohno, T., Sano, K., Morita, C., & Maeda, T. (2003). A novel electrolyzed sodium chloride solution fort the disinfection for dried HIV-1. *Bulletin of Osaka Medical College*, 48, 29-36.
Kiura, H., Sano, K., Morimatsu, S., Nakano, T., Morita, C., Yamaguchi, M., Maeda, T., & Katsuoka, Y. (2002). Bactericidal activity of electrolyzed acid water from solution containing sodium chloride at low concentration, in comparison with that at high concentration. *Journal of Microbiological Methods*, 49, 285-293. https://doi.org/10.1016/S0167-7012(01)00385-2
Koide, S., Takeda, J., Shi, J., Shono, H., & Atungulu, G.G. (2009). Disinfection efficacy of slightly acidic electrolyzed water on fresh cut cabbage. *Food Control*, 20, 294-297. https://doi.org/10.1016/j.foodcont.2008.05.019
Koseki, S., & Itoh, K. (2000). Fundamental properties of electrolyzed water. *Journal of the Japanese Society for Food Science and Technology*, 47, 390-393. http://doi.org/10.3136/nskkk.47.390
Koseki, S., & Itoh, K. (2001). Prediction of microbial growth in fresh-cut vegetables treated with acidic electrolyzed water during storage under various temperature conditions. *Journal of Food Protection*, 64, 1935-1942. https://doi.org/10.4315/0362-028X-64.12.1935
Koseki, S., Yoshida, K., Kamitani, Y., & Itoh, K. (2003). Influence of inoculation method, spot inoculation site, and inoculation size on the efficacy of acidic electrolyzed water against pathogens on lettuce. *Journal of Food Protection*, 66, 2010-2016. https://doi.org/10.4315/0362-028X-64.5.652
Krasaekoopt, W., & Bhandari, B. (2011). Fresh-cut vegetables. In: Sinha, N., Hui, Y.H., Evranuz, E. Ö., Siddiq, M., Ahmed, J. (Eds.), *Handbook of Vegetables and Vegetable Processing*, USA: Blackwell Publishing.
Len, S.V., Hung, Y.C., & Chung, D. (2002). Effects of storage conditions and pH on chlorine loss on electrolyzed oxidizing (EO) water. *Journal of Agriculture Food Chemistry*, 50, 209-212. http://doi.org/10.1021/jf010822v
Len, S.V., Hung, Y.C., Erickson, M.C., & Kim, C. (2000). Ultraviolet spectrophotometric characterization and bactericidal properties of electrolyzed oxidizing water as as influenced by amperage and pH. *Journal of Food Protection*, 63, 1534-1537. https://doi.org/10.4315/0362-028X-63.11.1534
Liao, L.B., Chen, W.M., & Xiao, X.M. (2007). The generation and inactivation mechanism of oxidation-reduction potential of electrolyzed oxidizing water. *Journal of Food Engineering*. 78, 1326-1332. https://doi.org/10.1016/j.jfoodeng.2006.01.004
Liu, R., He, X., Shi, J., Nirasawa, S., Tatsumi, E., Li, L., & Liu, H. (2013). The effect of electrolyzed water on decontamination, germination and γ-aminobutyric acid accumulation of brown rice. *Food Control*, 33, 1-5. https://doi.org/10.1016/j.foodcont.2013.02.008
Martínez-Hernández, G. B., Artés-Hernández, F., & Gómez, P.A. (2013). Combination of electrolyzed water, UV-C and superatmospheric O_2 packaging for improving fresh-cut broccoli quality. *Postharvest Biology and Technology*, 76, 125-136. https://doi.org/10.1016/j.postharvbio.2012.09.013
Morita, C., Sano, K., Moriatsu, S., Kiura, H., Goto, T., & Kohno, T. (2000). Disinfection potential of electrolyzed solutions containing sodium chloride at low concentrations. *Journal of Virological Methods*, 85,163-174. https://doi.org/10.1016/S0166-0934(99)00165-2
Nguyen-The, C. (2012). Biological hazards in processed fruits and vegetables - risk factors and impact of processing techniques. *LWT-Food Science and Technology*, 49, 172–177. https://doi.org/10.1016/j.lwt.2012.07.002
Olaimat, A.N., & Holley, R.A. (2012). Factors influencing the microbial safety of fresh produce: a review. *Food Microbiology*, 32 (1), 1–19. https://doi.org/10.1016/j.fm.2012.04.016

Ongeng, D., Devlieghere F., Debevere, J., Coosemans, J., & Ryckeboer, J. (2006). The efficacy of electrolyzed oxidizing water for inactivating spoilage microorganisms in process water and on minimally processed vegetables. *International Journal of Food Microbiology,* 109, 187-197. https://doi.org/10.1016/j.ijfoodmicro.2005.12.013

Ölmez, H., & Kretzschmar, U. (2009). Potential alternative disinfection methods for organic fresh-cut industry for minimizing water consumption and environmental impact. *LWT - Food Science and Technology,* 42, 686–693. https://doi.org/10.1016/j.lwt.2008.08.001

Pangloli, P., Hung, Y.C., Beuchat, L.R., Harold King, C., & Zhao, Z.H. (2009). Reduction of *Escherichia coli* O157:H7 on produce by use of electrolyzed water under simulated food service operation condition. *Journal of Food Protection,* 72, 1854-1861. https://doi.org/10.4315/0362-028X-72.9.1854

Park, C.M., Hung, Y.C., Doyle, M.P., Ezeike, G.O.I., & Kim, C. (2001). Pathogen reduction and quality of lettuce treated with electrolyzed oxidizing and acidified chlorinated water. *Journal of Food Science,* 66, 1368–1372. https://doi.org/10.1111/j.1365-2621.2001.tb15216.x

Park, H., Hung Y.C., & Chung, D. (2004). Effects of chlorine and pH on efficacy of electrolyzed water for inactivating *E. coli* O157:H7 and *L. monocytogenes. International Journal of Food Microbiology*. 91, 13-18. https://doi.org/10.1016/S0168-1605(03)00334-9

Phuvasate, S., & Su, Y.C. (2010). Effects of electrolyzed oxidizing water and ice treatments on reducing histamine-producing bacteria on fish skin and food contact surface. *Food Control*, 21, 286-291. https://doi.org/10.1016/j.foodcont.2009.06.007

Rahman, S.M.E., Ding, T., & Oh, D.H. (2010a). Inactivation effect of newly developed low concentration electrolyzed water and other sanitizers against microorganisms on spinach. *Food Control*, 21, 1383-1387. https://doi.org/10.1016/j.foodcont.2010.03.011

Rahman, S.M.E., Ding, T., & Oh, D.H. (2010b). Effectiveness of low concentration electrolyzed water to inactive foodborne pathogens under different environmental conditions. *International Journal of Food Microbiology*, 139, 147-153. https://doi.org/10.1016/j.ijfoodmicro.2010.03.020

Rico, D., Martín-Diana, A.B., Barry-Ryan, C., Frías, J.M., Henehan, G.T.M., & Barat, J. M. (2008). Use of neutral electrolyzed water (EW) for quality maintenance and shelf-life extension of minimally processed lettuce. *Innovative Food Science and Emerging Technologies,* 9, 37–48. https://doi.org/10.1016/j.ifset.2007.05.002

Rivera, E.V. (2005). A review of chemical disinfection methods for minimally processed leafy vegetables. Master of Science, Food Science Graduate Program College of Agriculture, Kansas State University, Manhattan: Kansas.

Sapers, G.M. (2014). Disinfection of contaminated produce with conventional washing and sanitizing technology. In: Matthews, K. R., Sapers, G.M., Gerba, C. P. (Eds.), *The Produce Contamination Problem: Causes and Solutions,* USA: Elsevier.

Sharma, R.R., & Demirci, A. (2003). Treatment of *Escherichia coli* O157:H7 inoculated alfaalfa seeds and sprouts with electrolyzed oxidizing water. *International Journal of Food Microbiology,* 86, 231-237. https://doi.org/10.1016/S0168-1605(02)00549-4

Sivapalasingam, S., Friedman, C.R., Cohen, L. & Tauxe, R.V. (2004). Fresh produce: a growing cause of outbreaks of foodborne illness in the United States. *Journal of Food Protection*, 67(10), 2342-2353. https://doi.org/10.4315/0362-028X-67.10.2342

Suzuki, K., Nakamura, T., Doi, T., Kokubo, S., & Tomita, M. (2005). The disinfectant effect of slightly acidic electrolyzed water prepared with hydrochloric acid as a raw material for lettuce. *Journal of Antibacterial and Antifungal Agents*, 33, 589-597.

Teixeira, P., & Rodriques, D. (2014). Antibiofilm agents from diagnosis to treatment and preservation. In: Rumbaugh, K. P., Ahmad, I. (Eds.), *Antibiofilm Strategies in the Food Industry,* Verlag: Springer.

Tomás-Callejas, A., Martínez-Hernández, G.B., Artés, F., & Artés-Hernández, F. (2011). Neutral and acidic electrolyzed water as emergent sanitizers for fresh-cut mizuna baby leaves. *Postharvest Biology and Technology*, 59, 298-306. https://doi.org/10.1016/j.postharvbio.2010.09.013

Turantaş, F., Başyiğit Kılıç, G., & Kılıç, B., (2015). Ultrasound in the meat industry: General applications and decontamination efficiency. *International Journal of Food Microbiology*, 198, 59-69. https://doi.org/10.1016/j.ijfoodmicro.2014.12.026

Ukuku, D.O., & Fett, W.F. (2006). Effect of cell surface charge and hydrophobicity on attachment of 16 *Salmonella serovars* to cantaloupe rind and decontamination with sanitizers. *Journal of Food Protection,* 69(8), 1835-1843. https://doi.org/10.4315/0362-028X-69.8.1835

Vandekinderen, I., Camp, J.V., Meulenaer, B.D., Veramme, K., Bernaert, N., Denon, Q., Ragaert, P., & Devlieghere, F. (2009). Moderate and high doses of sodium hypochlorite, neutral electrolyzed oxidizing water, peroxyacetic acid, and gaseous chlorine dioxide did not affect the nutritional and sensory qualities of fresh-cut iceberg lettuce (*Lactuca sativa Var.* capitata L.) after washing. *Journal of Agricultural and Food Chemistry,* 57, 4195-4203. http://doi.org/10.1021/jf803742v

Wang, H., Feng, H., & Luo, Y. (2004). Microbial reduction and storage quality of fresh-cut cilantro washed with acidic electrolyzed water and aqueous ozone. *Food Research International,* 37, 949-956. https://doi.org/10.1016/j.foodres.2004.06.004

Weissinger, W.R., Chantarapanont, W., & Beuchat, L.R. (2000). Survival and growth of *Salmonella baildon* in shredded lettuce and diced tomatoes, and effectiveness of chlorinated water as a sanitizer. *International Journal of Food Microbiology*, 62, 123–131. https://doi.org/10.1016/S0168-1605(00)00415-3

Whangchai, K., Saengnil, K., Singkamanee, C., & Uthaibutra, J. (2010). Effect of electrolyzed oxidizing water and continuous ozone exposure on the control of *Penicillium digitatum* on tangerine cv. 'Sai Nam Pung' during storage. *Crop Protection*. 29, 386-389. https://doi.org/10.1016/j.cropro.2009.12.024

Xiong, K., Liu, H. J., Liu, R., & Li, L.T. (2010). Differences in fungicidal efficiency against *Aspergillus flavus* for neutralized and acidic electrolyzed oxidizing water. *International Journal of Food Microbiology*, 137, 67-75. https://doi: 10.1016/j.ijfoodmicro.2009.10.032

Yang, H., Feirtag, J., & Diez-Gonzalez, F. (2013). Sanitizing effectiveness of commercial "active water" technologies on *Escherichia coli* O157:H7, *Salmonella enterica* and *Listeria monocytogenes*. *Food Control,* 33, 232-238. https://doi.org/10.1016/j.foodcont.2013.03.007

Yoshifumi, H. (2003). Improvement of the electrolysis equipment and application of slightly acidic electrolyzed water for dairy farming. *Journal of Japanese Society of Agriculture Machinery,* 65, 27-29. http://doi.org/10.11357/jsam1937.65.27

Zhang, C., Cao, W., Hung, Y. C., & Li, B. (2016). Application of electrolyzed oxidizing water in production of radish sprouts to reduce netural microbiota. *Food Control*, 67, 177-182. https://doi.org/10.1016/j.foodcont.2016.02.045

Zhang, C., Lu, Z., Li, Y., Shang, Y., Zhang, G., & Cao, W. (2011). Reduction of *Escherichia coli* O157:H7 and *Salmonella enteritidis* on mung bean seeds and sprouts by slightly electrolyzed water. *Food Control*. 22, 792-796. https://doi.org/10.1016/j.foodcont.2010.11.018