

Microbial Decontamination of Peeled Chestnuts by Electrolyzed Water and Its Effect on Biochemical and Sensory Properties (Penyahlumusan Mikrob Berangan Kupas oleh Air Elektrolisis dan Kesannya terhadap Sifat Biokimia dan Deria)

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ABSTRACT

The aim of this study was to improve the hygienic quality of peeled chestnuts by electrolyzed water (EW) treatment. Additionally, the effect of the treatment on biochemical and organoleptic properties of chestnuts was assessed. The counts of mesophilic aerobic bacteria (MAB) and yeasts and mold in peeled chestnuts were found to be 8.01 and 7.96 log CFU/g, respectively. Electrolyzed water was produced at four different combinations of brine and deionized water (A, B, C and D; with chlorine levels of 230, 470, 250 and 490 mg/L, respectively). Following treatment for 10 min using EW generated at the combination B (EW-B), the counts of MAB and yeasts and mold in peeled chestnuts were reduced by 1.61 and 1.65 log CFU/g, respectively, compared with distilled water treatment. Although EW-D possessed relatively high chlorine levels, its inactivation effect was found to be reduced after 5 min of treatment. Soluble solids and total phenolic content (TPC) of peeled chestnuts were decreased significantly ($p < 0.05$) with increasing EW treatment time. However, 2, 2-diphenyl-1-picrylhydrazyl free radical scavenging activity and sensory qualities were insignificantly altered by EW treatment. In conclusion, EW, especially EW-B, can potentially be used to reduce microbial load in peeled chestnuts with no or only minor negative effects on their biochemical and sensory qualities.

Keywords: Decontamination; electrolyzed water; peeled chestnut; sensory properties

ABSTRAK

Matlamat kajian ini adalah untuk meningkatkan kualiti kebersihan berangan kupas dengan rawatan air elektrolisis (EW). Selain itu, kesan daripada rawatan biokimia dan sifat organoleptik berangan telah dinilai. Kiraan bakteria mesofili aerobik (MAB) dan kulat serta acuan dalam berangan kupas adalah 8.01 dan 7.96 log CFU/g. Air elektrolisis telah dihasilkan pada empat gabungan berbeza air garam dan air nyahion (A, B, C dan D; dengan paras klorin pada 230, 470, 250 dan 490 mg/L). Rawatan lanjut untuk 10 minit menggunakan EW yang dihasilkan pada gabungan B (EW-B), kiraan MAB dan kulat serta acuan dalam berangan kupas telah dikurangkan sebanyak 1.61 dan 1.65 log CFU/g berbanding dengan rawatan air suling. Walaupun EW-D memiliki tahap klorin yang agak tinggi, kesan pentakaktifan didapati berkurangan selepas 5 minit rawatan. Pepejal larut dan jumlah kandungan fenol (TPC) berangan kupas berkurangan dengan ketara ($p < 0.05$) dengan peningkatan masa rawatan EW. Walau bagaimanapun, aktiviti skaveng radikal bebas dan kualiti deria 2, 2-difenil-1-pikrilterasil telah diubah dengan ketara oleh rawatan EW. Kesimpulannya, EW, terutamanya EW-B, berpotensi digunakan untuk mengurangkan beban mikrob dalam berangan kupas tanpa atau sedikit kesan negatif dalam kualiti biokimia dan deria mereka.

Kata kunci: Air elektrolisis; berangan kupas; penyahlumusan; sifat deria

INTRODUCTION

Sweet chestnut (*Castanea sativa* Mill.) is a deciduous broadleaf tree belonging to the family Fagaceae; and it is native to temperate regions of the Northern Hemisphere. In raw chestnut seed, the levels of water, starch, crude protein, crude fat and crude fiber contents were reported to be approx. 60%, 30%, 6%, 1% and 2%, respectively (Kim et al. 2014; Park et al. 1998). Chestnut is also a rich source of vitamins (B-complex and C) and tannins (composed of caffeic acid, ferulic acid, sinapic acid and salicylic acid) (Park et al. 1998) and a key ingredient in the development of different processed foods (Lee et al. 2016).

Consumer demand for peeled chestnuts has continued to increase due to the growing need for fresh, healthy, appetizing and convenient foods (Kader 2002). Different mechanical de-shelling technologies are used to produce peeled chestnuts. However, the removal of the shell and pellicle (which act as natural physical barrier that protects the kernel) can cause the loss of water and contamination of the kernel with opportunistic microorganisms and pathogens (Cantwell 1995; Mencarelli 2001), which negatively affect final quality and safety (Field et al. 2006). In an earlier study, average contamination levels of mesophilic aerobic bacteria (MAB), yeast and molds in freshly harvested and unpeeled chestnuts were shown to be 2.70, 2.74 and 2.51

log CFU/g, respectively (Donis-Gonzalez et al. 2017). However, the levels of these contaminants were reported to be significantly altered during peeling (3.46, 3.27 and 2.40 log CFU/g) and post-peeling (5.39, 3.09 and <1.70 log CFU/g), respectively. In addition, both bacteria and yeast species, namely *Curtobacterium* sp., *Rahnella* sp. and *Candida* sp., were shown to be the predominant cause of spoilage. Hence, post-processing sanitizer treatments have been recommended to prevent undesirable spoilage of peeled chestnuts (Donis-Gonzalez et al. 2017).

Chlorine in the chemical form of hypochlorous acid and hypochlorite has been extensively used in the food industry, especially the fresh-cut industry, as a disinfectant (Meireles et al. 2016). However, treating with chlorine does not always yield meaningful microbial reduction (including foodborne pathogens) and can also lead to the formation of carcinogenic by-products (Donis-Gonzalez et al. 2017; Vitro et al. 2005). In a study, eco-friendly techniques including warm water (65°C) immersion, 2,700 ppm hydrogen peroxide (H₂O₂) + 200 ppm peracetic acid (CH₃CO₃H) and X-ray irradiation (0.5, 1.0, 1.5 and 2.0 kGy) were found to be most effective for aerobic bacteria and yeast reduction in peeled chestnuts (Donis-Gonzalez et al. 2017).

In recent years, the use of non-chemical and non-thermal agents as an alternative to conventional sanitizers for decontamination is gaining popularity in the food industry. Among such agents, electrolyzed water (EW) is increasingly being recognized as a novel, safe, and wide-spectrum disinfectant. It can be used in a range of applications including food sanitation, agriculture, livestock management, medical sterilization and others (Huang et al. 2008; Rahman et al. 2016). Electrolyzed water is produced in an electrolysis chamber (which contain cathode and anode separated by a diaphragm) containing dilute NaCl solution (Hricova et al. 2008; Rahman et al. 2016). Electrolyzed water is considered more environmentally friendly compared with chlorinated sanitizers since it readily converts to ordinary water on dilution by tap/reverse osmosis water or upon contact with organic matter (Huang et al. 2008). For the purpose of food sanitation, the application of acidic and neutral types of EW has been recommended (Artes et al. 2009; Puligundla et al. 2018). Strong germicidal effect of acidic EW has been shown previously (Hricova et al. 2008). In a study, washing with warm (45°C) slightly acidic EW (pH5.5) was found effective in the reduction of total aerobic bacteria as well as molds and yeasts (by 2.2 and >1.9 log₁₀ CFU/g, respectively) on sliced carrot when compared with tap water washing (Koide et al. 2011).

Therefore, in this study, an attempt was made to produce EW suitable for the sanitation of peeled chestnuts. The microbicidal potential of EW against naturally occurring microbial contaminants of peeled chestnuts was evaluated. In addition, possible impacts of EW treatment on the biochemical and sensory properties of peeled chestnuts were determined.

MATERIALS AND METHODS

CHESTNUTS

Peeled chestnuts were procured (from different lots) locally from Cheongpyeong (Gapyeong County, Korea) (in January 2017) and they were stored at 4°C until use (within 48 h).

PRODUCTION OF ELECTROLYZED WATER

Electrolyzed water suitable for the treatment of peeled chestnuts was produced using an electrolyzed water system (model ENOGEN 40P, Dyeco, Seongnam, Korea). The dimensions of various components of the unit and operating conditions has been discussed in our earlier study (Puligundla et al. 2018). Briefly, during EW generation, saturated NaCl solution (brine) and deionized water were continuously fed into the system. Following the electrolysis of these solutions, two distinct products were formed; viz. anolyte solution with pH ~2-3 and catholyte solution with pH ~11-12. The flow rates of brine as well as deionized water were optimized to produce EW suitable for peeled chestnut decontamination (i.e. to produce moderately acidic or neutral EW devoid of offensive chlorine odor). In the EW generator, a portion of the catholyte solution was redirected to the anolyte chamber, resulted in a progressive pH shift of the anolyte outflow stream from highly acidic to neutral. The flow rates of brine and deionized water were adjusted in such a way to obtain EW with no disagreeable odor.

The concentration of free chlorine and pH of EW were determined using a portable photometer (Model HI 95711, Hanna Instruments, Woonsocket, RI, USA) and a Mettler Toledo 320 pH meter, respectively. In addition, the salinity of EW was analyzed using a salinity tester (Model SB1500pro, HM Digital, Seoul, Korea). Conductivity was determined using Orion analyzer (Model 1260, Orion Research Inc., USA).

TREATMENT USING EW

Peeled chestnuts (each sample 10 g; three replications per treatment) placed in a stainless steel mesh strainer with a chain to hold were treated by EW (one liter) via immersion for predetermined durations. The immersion times ranged from 2.5 to 10 min. After that, they were subjected to residual microbial analysis as well as biochemical and sensory characterization. Distilled water (DW) treated peeled chestnuts were used as positive controls, and untreated peeled chestnuts served as negative controls.

CONTAMINANT DETECTION AND ESTIMATION OF RESIDUAL COUNTS

Natural microbial contaminants of peeled chestnuts were detected using general-purpose as well as selective enrichment media. Microbial culture media used in this study were procured from Becton Dickinson and Co. (Sparks, MD, USA). Total viable counts of contaminants

were quantified according to the standard plate count method (KFDA 2011). Peeled chestnuts (10 g each) were taken into filter stomacher bags (3M Korea, Seoul) and sterile 0.85% (w/v) NaCl solution (90 mL) was added to each bag. Subsequently, the bagged samples were homogenized using a paddle blender (Masticator, IUL Instruments, Barcelona, Spain) for 2 min at 8.0 strokes/s. Thereafter, aliquots of 1.0 mL of each sample were aseptically removed from the bag filtrates, diluted serially with 0.85% sterile saline, and then transferred to 90 mm diameter Petri plates (according to pour plate method) containing either general-purpose or selective agar media. Finally, the incubation of the plates was carried out at 37°C for 24–48 h. Plate count agar (PCA) and potato dextrose agar (PDA) (both are general purpose media) were used for determining the counts of MAB and yeasts and molds, respectively. In addition, selective enrichment media including mannitol-egg yolk-polymyxin agar, eosin-methylene blue agar, Baird-Parker agar, xylose-lysine-deoxycholate agar, and PALCAM medium base agar were used for the detection of *Bacillus cereus*, *Escherichia coli*, *Staphylococcus aureus*, *Salmonella* spp., and *Listeria monocytogenes*, respectively.

Following EW treatment, 10 g peeled chestnuts from each treatment were taken into individual stomacher bags and 0.85% sterile saline was added (90 mL to each bag). Thereafter, the samples were homogenized for 3 min and filtered. The filtrates were subjected to viable microbial analysis according to the aforementioned procedure.

MODELING OF INACTIVATION

The first-order inactivation model is generally employed to explain survivor curves from lethal agents, assuming a linear logarithmic decrease in survivors count over treatment period, as given in (1) (Puligundla et al. 2018).

$$\log \frac{N_0}{N} = \frac{k}{2.303} \cdot t \quad (1)$$

where N_0 is initial microbial counts; N is microbial counts at time t ; k is inactivation rate constant; and t is exposure time (min).

$$D = \frac{2.303}{k} \quad (2)$$

where D is decimal reduction time (min).

SOLUBLE SOLIDS CONTENT

Peeled chestnuts were homogenized for 60 s in a blender (Model HR 2860, Royal Philips Electronics NV, Amsterdam, The Netherlands) and then filtered soluble solids content was measured using a refractometer (SCM-1000, HM Digital, Seoul, Korea). The value of soluble solids was expressed as °Brix.

PREPARATION OF PEELED CHESTNUTS FOR BIOCHEMICAL ANALYSIS

Peeled chestnuts from each treatment condition were taken and ground for 60 s using a blender (HR 2860, Royal Philips Electronics NV, Amsterdam, Netherlands) and lyophilized using a freeze dryer (FD 5505, Ilshin Lab Corp., Yangju, Korea). One gram of each lyophilized sample was dissolved in a mixture of distilled water/methanol/5N hydrochloric acid (26:50:24) according to the method described by Singleton and Rossi (1965) and incubated at 30°C in a constant temperature water bath (Ultra, SejongPlus, Ilsan, Korea) for 2 h. Then the mixture was centrifuged at $2400 \times g$ for 3 min using a centrifuge (DM0412, Proneer, Gunpo, Korea) and the resultant supernatant (hereinafter referred to as 'the extract') was taken for analysis.

DPPH radical scavenging ability The DPPH (2, 2-diphenyl-1-picrylhydrazyl) radical scavenging activity of the extracts was determined according to the method described by Blois (1958) using the following formula:

Scavenging activity (%)

$$= \left(\frac{A_{517} \text{ of control} - A_{517} \text{ of sample}}{A_{517} \text{ of control}} \right) \times 100$$

where A_{517} is absorbance at 517 nm.

Total phenolic content Total phenolic content of the extracts was measured according to the method described earlier (Singleton & Rossi 1965) using Folin-Ciocalteu reagent. Results are expressed as μg gallic acid equivalents (GAE)/g.

SENSORY EVALUATION

During sensory evaluation, the samples of untreated, DW-treated and EW-treated peeled chestnuts were presented to a panel of untrained students (12) from our department in the university for scoring quality characteristics, namely appearance, flavor. Also, overall acceptability was estimated as the average of scores given for these properties. The degree of liking or dislike was determined using a 9-point hedonic scale (1=dislike extremely, 9=like extremely).

STATISTICAL ANALYSIS

Three replicates were used for each experimental condition and results are presented as the mean \pm standard deviation (SD). For performing statistical analyses, the SAS statistical software package (version 9.2, SAS Institute Inc., Cary, NC) was used. And, for analyzing the variance ($p < 0.05$) of the data, one-way ANOVA followed by Duncan's multiple range tests were used.

RESULTS AND DISCUSSION

MICROBIAL CONTAMINANTS

Mesophilic aerobic bacteria as well as yeasts and mold were found as contaminants in peeled chestnuts. Their levels were relatively high, the mean \pm SD levels of MAB and yeasts and mold were 8.01 ± 0.56 and 7.96 ± 0.64 log CFU/g, respectively. However, common foodborne pathogenic microorganisms, including *E. coli*, *B. cereus*, *S. aureus*, *Salmonella* spp. and *L. monocytogenes*, were not detected in the tested samples.

Nuts are generally not associated with foodborne outbreaks (Uesugi et al. 2006). However, salmonellosis outbreak in 2004 has been shown to be linked to the consumption of contaminated raw almonds. In addition, the consumption of mixed nuts and peanuts has been linked to salmonellosis in Vermont and South Carolina in 2006 (CDC 2006). As chestnuts possess a relatively higher moisture content (moisture level \sim 12%) (Beuchat 1978), there is a greater possibility for survival of spoilage and pathogenic microorganisms in peeled chestnuts once contamination occurs. Increased levels of spoilage microorganisms in chestnuts during peeling and post-peeling stages have been reported (Donis-Gonzalez et al. 2017). This clearly indicates the cross-contamination during peeling process and further survival of contaminants in peeled chestnuts.

PRODUCTION OF EW SUITABLE FOR PEELED CHESTNUT DECONTAMINATION

Electrolyzed water produced at brine pump settings of 20 and 40 and at pH pump settings of 60, 80 and 100 exhibited no disagreeable odor, as shown in Figure 1. At 20 \times 60, 20 \times 80, 40 \times 60 and 40 \times 80 settings, brine in-flow rates were 2.73 ± 0.06 , 2.67 ± 0.06 , 4.57 ± 0.06 and 4.60 ± 0.00 mL/min; alkali out-flow rates were 442 ± 7.64 , 493 ± 2.89 , 438 ± 2.89 , 507 ± 5.77 mL/min, respectively. At these flow settings, EW generated at combination A (EW-A), B (EW-B), C (EW-C) and D (EW-D) contained chlorine at levels of 230, 470, 250 and 490 mg/L; pH values were 3.66, 3.27, 4.56 and 3.15, respectively. In addition, conductivity and salinity

of EW-A, EW-B, EW-C and EW-D were 3020, 4570, 2825 and 3910 μ S/cm and 0.23, 0.31, 0.18 and 0.26%, respectively.

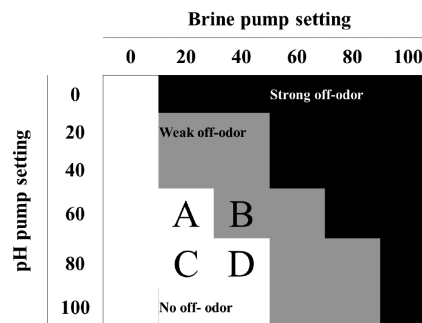


FIGURE 1. Off-odor (chlorine-like) levels in produced electrolyzed water at different pH and brine pump settings

PEELED CHESTNUT TREATMENT USING EW

Compared with untreated peeled chestnuts, as high as 1.42, 1.61, 1.40 and 1.37 log CFU/g reductions of initial counts of MAB were observed upon treatment (for 10 min) of peeled chestnuts using EW-A, EW-B, EW-C and EW-D, respectively. In addition, during the same treatment period, yeasts and mold were decreased by 1.53, 1.65, 1.47 and 1.39 log CFU/g using EW-A, EW-B, EW-C and EW-D, respectively. The differences between the disinfection effectiveness of the four types of EW are not significant. However, DW treatment exhibited relatively low levels of reduction of both MAB and yeasts and mold as shown in Figure 2.

Fresh produce decontamination by acidic EW treatment has been shown in previous studies. A significant reduction in the viable counts of natural microflora on fresh-cut cilantro was observed following slightly acidic EW treatment; reductions as high as 1.08, 1.56 and 1.64 log CFU/g were noted for coliform bacteria, total aerobic bacteria and yeasts and mold, respectively, following the treatment for 5 min (Hao et al. 2011). In another study, upon the application of slightly acidic electrolyzed water for sanitizing cherry tomatoes, total aerobic bacteria and

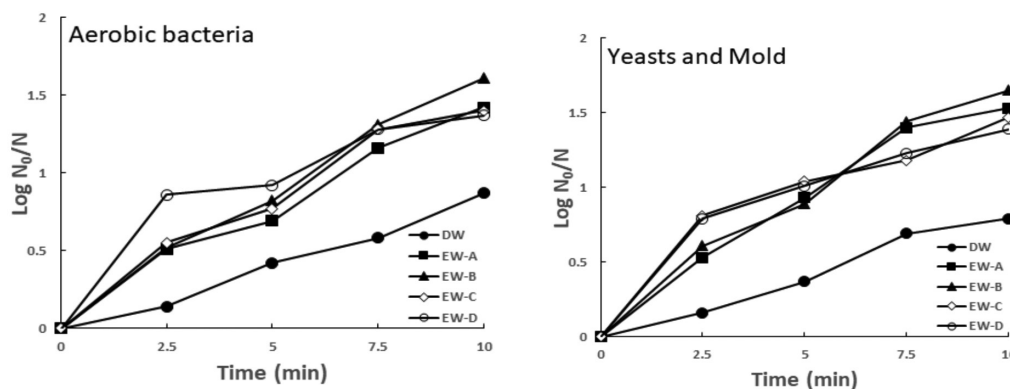


FIGURE 2. The pattern of inactivation of microbial contaminants of peeled chestnuts by electrolyzed water treatment

yeasts and mold were reduced by 1.45 and 1.10 log CFU/g, respectively (Ding et al. 2015).

Limited information is available regarding the mechanism of microbicidal action of EW; active chlorine species (Cl_2 , HOCl , $-\text{OCl}$) of EW are known to contribute to microbial cell inactivation (Rahman et al. 2016). In addition to chlorine species, oxidants such as ROS (especially O_3 and H_2O_2) formed during electrolysis have been shown to contribute to the microbicidal efficiency of EW (Jeong et al. 2009). Low pH of acidic EW suppresses bacterial growth and it even makes microbes more vulnerable to dynamic chlorine (Rahman et al. 2016).

D-VALUE

D-value refers to decimal reduction time. *D*-values observed for MAB upon treatment by EW-A, EW-B, EW-C and EW-D were 6.80, 5.98, 6.51 and 6.24 min, respectively; whereas in the case of yeasts and mold inactivation, *D*-values were 5.91, 5.64, 6.09 and 6.21 min, respectively. These results indicate that both MAB and yeasts and mold were relatively more susceptible to EW-B compared with others.

SOLUBLE SOLIDS CONTENT

Soluble solids content of peeled chestnuts before EW treatment was found to be 19.90 °Bx. On treating with distilled water, no significant decrease of soluble solids content was observed; 18.60 °Bx at 2.5 min, 17.73 °Bx at 5 min, 17.67 °Bx at 7.5 min, and 17.53 °Bx at 10 min (Figure 3). In the case of EW treatment, soluble solids content of peeled chestnuts following the treatment (using EW-A, EW-B, EW-C and EW-D) for 10 min were 20.00, 18.07, 16.57 and 18.50 °Bx, respectively. All EW treatments showed no significant ($p > 0.05$) impact on soluble solids content except with EW-C, which exerted a significant ($p < 0.05$) decrease.

DPPH RADICAL SCAVENGING ABILITY

The DPPH radical scavenging activity is a measure of antioxidant activity and can be used to measure antioxidant activity based on the electron donating activity of DPPH (Kim et al. 2014). The average level of DPPH radical scavenging activity of untreated peeled chestnuts was

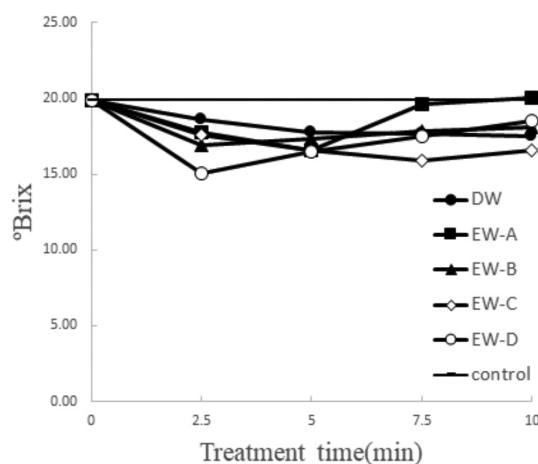


FIGURE 3. Changes in soluble solids content of peeled chestnuts by electrolyzed water treatment

66.41%, and this ability was not significantly ($P > 0.05$) altered (66.92% at 10 min) when treated with distilled water. In addition, slight (insignificant) reductions were noted upon treatment (2.5-10 min) with EW-A (67.08% to 64.69%), EW-B (67.94% to 65.14%), EW-C (67.69% to 65.68%), and EW-D (66.73% to 64.66%).

TOTAL PHENOLIC CONTENT (TPC)

In untreated peeled chestnuts, total phenolic content was $265.4 \pm 26.4 \mu\text{g GAE/g}$. In DW and EW-treated samples, exposure time-dependent decrease in the levels of phenolic content was noted. After treatment for 10 min, total phenolic content in DW-treated samples was significantly ($p < 0.05$) decreased to $217.5 \pm 18.6 \mu\text{g GAE/g}$; and average levels in samples treated by EW-A, EW-B, EW-C and EW-D were 204.3 ± 5.8 , 235.7 ± 20.5 , 222.0 ± 1.8 and $239.6 \pm 7.3 \mu\text{g GAE/g}$, respectively (Table 1). Similar results were obtained when peeled lotus roots were stored in strong acidic electrolyzed water (SAEW, pH 2.76, ORP 1,128 mV, HClO 105.0 ppm) - total phenolic content of peeled lotus roots stored in SAEW was lower than that of one stored in tap water (Jeong et al. 2006). Most phenolic compounds are rich sources of natural antioxidants; and they are closely associated with nutritional and sensory quality of fresh and processed plant foods (Ho 1992).

TABLE 1. Changes in total phenolic content (TPC) of peeled chestnuts by electrolyzed water treatment

Treatment time (min)	DW	EW-A	EW-B	EW-C	EW-D
0	265.4 ± 26.4^a	265.4 ± 26.4^a	265.4 ± 26.4^{ab}	265.4 ± 26.4^{ab}	265.4 ± 26.4^{ab}
2.5	250.4 ± 19.9^{ab}	244.0 ± 32.5^a	271.0 ± 24.3^a	258.7 ± 5.0^a	268.9 ± 17.2^a
5	250.1 ± 32.0^{ab}	246.4 ± 2.1^a	235.1 ± 23.1^{ab}	238.6 ± 42.1^a	251.5 ± 11.0^{ab}
7.5	235.9 ± 18.7^{ab}	244.5 ± 24.8^a	233.4 ± 2.6^b	222.2 ± 38.0^a	260.5 ± 1.8^{ab}
10	217.5 ± 18.6^b	204.3 ± 5.8^b	235.7 ± 20.5^{ab}	222.0 ± 1.8^a	239.6 ± 7.3^b

DW: distilled water; EW: electrolyzed water; Means in the same column followed by the same letter are not significantly ($p > 0.05$) different by Duncan's multiple range test

TABLE 2. Effect of electrolyzed water washing on sensory properties of peeled chestnuts

Disinfectant	Treatment time (min)	Sensory properties			
		Appearance	Color	Flavor	Overall acceptance
	Control	5.00 ± 1.97 ^a	5.80 ± 2.10 ^a	5.90 ± 1.29 ^a	5.60 ± 1.78 ^a
DW	2.5	6.30 ± 1.25 ^a	6.30 ± 1.83 ^a	6.60 ± 1.35 ^a	6.60 ± 1.17 ^a
	5	6.10 ± 1.66 ^a	7.00 ± 1.33 ^a	6.60 ± 1.07 ^a	6.40 ± 1.35 ^a
	7.5	6.90 ± 1.29 ^a	6.70 ± 1.57 ^a	6.40 ± 1.51 ^a	6.70 ± 1.49 ^a
	10	6.40 ± 1.58 ^{ab}	6.00 ± 1.83 ^a	6.30 ± 2.16 ^a	6.50 ± 1.65 ^a
EW-A	2.5	6.30 ± 1.49 ^{ab}	6.90 ± 1.60 ^a	6.20 ± 1.14 ^a	6.30 ± 1.34 ^a
	5	6.50 ± 1.51 ^{ab}	6.50 ± 1.65 ^a	6.50 ± 0.97 ^a	6.50 ± 1.18 ^a
	7.5	5.90 ± 2.08 ^{ab}	6.20 ± 1.40 ^a	6.80 ± 1.23 ^a	6.40 ± 1.43 ^a
	10	6.50 ± 1.65 ^{ab}	6.40 ± 1.43 ^a	6.30 ± 1.42 ^a	6.60 ± 1.71 ^a
EW-B	2.5	6.30 ± 1.83 ^{ab}	6.10 ± 1.52 ^a	5.70 ± 1.25 ^a	6.30 ± 1.57 ^a
	5	5.90 ± 1.45 ^{ab}	6.10 ± 1.52 ^a	6.30 ± 0.95 ^a	6.30 ± 1.25 ^a
	7.5	5.90 ± 1.10 ^{ab}	6.40 ± 1.58 ^a	6.10 ± 1.10 ^a	6.20 ± 1.14 ^a
	10	5.30 ± 1.25 ^{ab}	5.40 ± 1.58 ^a	6.00 ± 1.05 ^a	5.50 ± 1.35 ^a
EW-C	2.5	5.90 ± 2.02 ^{ab}	6.50 ± 1.78 ^a	6.20 ± 1.23 ^a	6.10 ± 1.66 ^a
	5	6.20 ± 1.48 ^{ab}	6.00 ± 1.56 ^a	6.20 ± 1.48 ^a	6.20 ± 1.48 ^a
	7.5	6.10 ± 1.52 ^{ab}	6.10 ± 1.29 ^a	5.90 ± 1.29 ^a	6.10 ± 1.20 ^a
	10	6.40 ± 1.07 ^{ab}	6.20 ± 1.03 ^a	6.60 ± 1.43 ^a	6.30 ± 0.82 ^a
EW-D	2.5	5.60 ± 1.65 ^{ab}	6.20 ± 1.23 ^a	6.20 ± 1.23 ^a	5.80 ± 1.03 ^a
	5	6.80 ± 1.14 ^{ab}	6.40 ± 1.71 ^a	6.60 ± 1.26 ^a	6.70 ± 1.16 ^a
	7.5	6.10 ± 1.37 ^a	5.90 ± 1.52 ^a	6.00 ± 1.25 ^a	6.20 ± 1.23 ^a
	10	5.90 ± 1.60 ^a	5.80 ± 1.81 ^a	6.10 ± 1.10 ^a	6.00 ± 1.49 ^a

1: very poor, 5: moderate, 9: very good; Judged by 10 panelists using 9-point hedonic scale; Values with same letters within same row are not significantly different ($p < 0.05$)

SENSORY CHARACTERISTICS

Compared to untreated controls, sensory properties (appearance, color and flavor) of DW and EW-treated (2.5-10 min) peeled chestnuts were not significantly ($p > 0.05$) different (Table 2). However, DW and EW treatment contributed to relatively better appearance, color and flavor characteristics. Therefore, overall acceptance was not significantly altered following the treatment by DW or EW (EW-A, EW-B, EW-C and EW-D). Similar results have been reported in a study by Kim et al. (2007), wherein the soaking of peeled chestnuts in electrolyzed oxidizing water (pH 2.61, ORP 1,142 mV) for 10 min did not affect the edible quality of the nuts.

CONCLUSION

The purpose of the present work was to enhance the hygienic quality of peeled chestnuts using electrolyzed water. Mesophilic aerobic bacteria as well as yeasts and mold were found as contaminants at high levels. The highest bactericidal effect was observed with treatment using EW-B; MAB and yeasts and mold were decreased by 1.61 and 1.65 log CFU/g following treatment for 10 min, respectively. Soluble solids content and total phenolic content of peeled chestnuts were significantly decreased with increasing treatment time. On the contrary, DPPH radical scavenging ability was not significantly altered by

EW treatment. In addition, sensory characteristics were not affected by EW treatment. Since quality and nutritional value are the most important attributes influencing purchase and consumption decisions, EW treatment of peeled chestnuts can maintain these attributes.

Combination treatments with other eco-friendly antimicrobial agents (weak organic acids) or processes (ultra-sonication) could further increase the sanitizing efficiency of EW. Therefore, more studies need to be conducted in order to examine possible synergistic effects of EW in combination with other microbicides.

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REFERENCES

- Artes, F., Gomez, P., Aguayo, E., Escalona, V. & Artes-Hernandez, F. 2009. Sustainable sanitation techniques for keeping quality and safety of fresh-cut plant commodities. *Postharvest Biology and Technology* 51: 287-296.
- Beuchat, L.R. 1978. Relationship of water activity to moisture content in tree nuts. *Journal of Food Science* 43: 754-755, 758.
- Blois, M.S. 1958. Antioxidant determination by the use of a stable free radical. *Nature* 181: 1199-1200.
- Cantwell, M.C. 1995. Food safety: Microbial concerns. *Perishables Handling Newsletter* 81: 15-16.

- Center for Disease Control and Prevention (CDC). 2006. *Surveillance for Foodborne-Disease Outbreaks-United States*. CDC. Atlanta, GA: MMWR.
- Ding, T., Ge, Z., Shi, J., Xu, Y.T., Jones, C.L. & Liu, D.H. 2015. Impact of slightly acidic electrolyzed water (SAEW) and ultrasound on microbial loads and quality of fresh fruits. *LWT - Food Science and Technology* 60(Part 2): 1195-1199.
- Donis-Gonzalez, I.R., Jeong, S., Guyer, D.E. & Fulbright, D.W. 2017. Microbial contamination in peeled chestnuts and the efficacy of postprocessing treatments for microbial spoilage management. *Journal of Food Processing and Preservation* 41(2): e12874.
- Field, B., Jordan, F. & Osbourn, A. 2006. First encounters-deployment of defence-related natural products by plants. *New Phytologist* 172: 193-207.
- Hao, J.X., Liu, H.J., Liu, R., Dalai, W.Y., Zhao, R.P., Chen, T.P. & Li, L.T. 2011. Efficacy of slightly acidic electrolyzed water (SAEW) for reducing microbial contamination on fresh-cut cilantro. *Journal of Food Safety* 31: 28-34.
- Ho, C.T. 1992. Phenolic compounds in food: An overview. In *Phenolic Compounds in Food and their Effects on Health I, Analysis, Occurrence and Chemistry*, edited by Ho, C.T., Lee, C.Y. & Huang, M.T. Washington D.C.: American Chemical Society. Vol. 506(Chapter 1): pp. 2-7.
- Hricova, D., Stephan, R. & Zweifel, C. 2008. Electrolyzed water and its application in the food industry. *Journal of Food Protection* 71(9): 1934-1947.
- 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.
- Jeong, J., Kim, C. & Yoon, J. 2009. The effect of electrode material on the generation of oxidants and microbial inactivation in the electrochemical disinfection processes. *Water Research* 43: 895-901.
- Jeong, J.W., Park, K.J., Sung, J.M., Kim, J.H. & Kwon, K.H. 2006. Comparison of quality of peeled lotus roots stored in various immersion liquids during storage. *Korean Journal of Food Science and Technology* 38(4): 526-533.
- Kader, A.A. 2002. *Postharvest Technology of Horticultural Crops*. 3rd ed. California: Regents of the University of California, Division of Agriculture and Natural Resources.
- KFDA 2011. *Korean Food Standards Codex (Vol. 2)*. Chungbuk, Korea: Korea Food and Drug Administration. pp. 9.3.1.1-9.3.18.2.
- Kim, J.H., Jeong, J.W. & Kweon, K.H. 2007. Quality effects of various pretreatment methods on the properties of peeled chestnut during storage. *Korean Journal of Food Preservation* 14(5): 462-468.
- Kim, J.Y., Kim, S.Y., Kwon, H.M., Kim, C.H., Lee, S.J., Park, S.C. & Kim, K.H. 2014. Comparison of antioxidant and anti-inflammatory activity on chestnut, chestnut shell and leaves of *Castanea crenata* extracts. *Korean Journal of Medicinal Crop Science* 22(1): 8-16.
- Koide, S., Shitanda, D., Note, M. & Cao, W. 2011. Effects of mildly heated, slightly acidic electrolyzed water on the disinfection and physicochemical properties of sliced carrot. *Food Control* 22: 452-456.
- Lee, H.S., Jang, Y.J. & Kim, S.H. 2016. The study on development of processed foods with chestnut. *Journal of The Korean Society of Food Culture* 31(2): 194-203.
- Meireles, A., Giaouris, E. & Simoes, M. 2016. Alternative disinfection methods to chlorine for use in the fresh-cut industry. *Food Research International* 82: 71-85.
- Mencarelli, F. 2001. *Postharvest Handling and Storage of Chestnuts, Food and Agriculture Organization of the United Nations*. XinXian, Henana, China.
- Park, S., Kang, J.Y. & Kang, S.C. 1998. Improvement in storage stability of export peeled-chestnuts using electrolyzed acid-water. *Journal of the Korean Society for Applied Biological Chemistry* 41(7): 545-549.
- Puligundla, P., Kim, J.W. & Mok, C. 2018. Broccoli sprout washing with electrolyzed water: Effects on microbiological and physicochemical characteristics. *LWT - Food Science and Technology* 92: 600-606.
- Rahman, S.M.E., Khan, I. & Oh, D.H. 2016. Electrolyzed water as a novel sanitizer in the food industry: Current trends and future perspectives. *Comprehensive Reviews in Food Science and Food Safety* 15: 471-490.
- Singleton, V.L. & Rossi, J.A. 1965. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture* 16: 144-158.
- Uesugi, A.R., Danyluk, M.D. & Harris, L.J. 2006. Survival of *Salmonella* Enteritidis phage type 30 on inoculated almonds stored at -20, 4, 23, and 35°C. *Journal of Food Protection* 69(8): 1851-1857.
- Vitro, R., Sanz, D., Alvarez, I., Condon, S. & Raso, J. 2005. Comparison of the chlorine inactivation of *Yersinia enterocolitica* in chlorine demand and demand-free systems. *Journal of Food Protection* 68: 1816-1822.

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