Decontamination of collards (*Brassica oleracea* var. *acephala* L.) using electrolyzed water and corona discharge plasma jet

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Abstract Acidic electrolyzed water (AEW) was used for collards sanitization. In the AEW (pH of 3.6; 230 mg/L chlorine) generator, the rates of brine inflow and catholyte outflow were 2.73 and 442 mL/min, respectively. Following treatment of the collards with the AEW alone (5 min), the counts of aerobic bacterial contaminants were reduced by 1.91 log CFU/g, whereas 2.22 log CFU/g reduction was noted by the AEW soaking (5 min) followed by a corona discharge plasma jet treatment (1 min). In a similar manner, the counts of yeasts and mold contaminants were reduced (1.48 and 1.75 log CFU/g, respectively). The combination treatment exhibited an additive effect on the microbial inactivation. The combined treatment did not affect significantly the DPPH-radical scavenging activity and sensory properties (appearance, color and flavor) of the collards compared to negative controls. However, significant alterations in the levels of total phenolics and ascorbic acid were observed post-treatment.

Keywords Collard · Decontamination · Electrolyzed water · Corona discharge plasma jet · Sensory quality

Introduction

Collards or collard greens are a kind of leafy vegetable, rich in nutritionally important minerals like potassium, calcium and iron and vitamins like A, C and K. These are

botanically related to broccoli, kale, cabbage, Brussels sprouts and other members of the cabbage family of vegetables. Raw collard greens are widely used in the preparation of a variety of salads. Regular consumption of vegetables has been linked to a lower risk of obesity, cardiovascular diseases, cancer and others (Ignarro et al., 2007). Despite several health benefits associated with nutrients in leafy greens, the risk of microbial contamination on them is a concern (Maffei et al., 2013). In a study, it has been shown that all varieties of tested vegetables, including collard greens, were contaminated with *Escherichia coli* and total coliforms, apart from mesophilic aerobic bacteria and yeasts and molds (Maffei et al., 2013). Several foodborne illnesses have been shown to be associated with the consumption of contaminated fresh produce (FAO/WHO, 2008).

In order to decrease or eliminate the microbial load of fresh produce and to maintain microbial safety, several decontamination strategies have been proposed. Aqueous chlorine is the widely used disinfectant in the fresh-cut produce industry due to its effectiveness against vegetative bacteria and some enteric viruses, and also due to reliable availability and low cost (Van Haute et al., 2013). In addition, chlorine as a sanitizer exerts minimal impact on the sensorial and nutritional quality of fresh produce (Parish et al., 2003). However, the soaking and rinsing of fresh-cut leafy greens in chlorinated water (with 100 mg/L chlorine) has been shown to be less effective in terms of microbial inactivation, besides the formation of carcinogenic by-products and resistance initiation in microorganisms (Monnin et al., 2012; Puligundla et al., 2018). Therefore, non-chemical and eco-friendly sanitization methods using disinfectants such as electrolyzed water, ionizing radiation, ozone and nonthermal or cold plasma, among others, are gaining significance. Treatment with

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ionizing radiation (gamma radiation) significantly reduced (up to 3 log CFU/g) the viable counts of total aerobic bacteria in cilantro, without adverse effects on the sensorial quality and shelf life of the herb (Fan et al., 2003). In a previous study, upon broccoli sprout washing with acidic electrolyzed water for a cumulative period of 20 s, the viable counts of aerobic bacteria and molds and yeasts were decreased by 1.4 and 1.0 log CFU/g, respectively (Puligundla et al., 2018).

Nonthermal plasma can be used for decontamination of heat-sensitive materials, including fresh foods. Unlike food irradiation (i.e. the exposure of food to ionizing radiation), nonthermal plasmas can be easily produced without the need for expensive equipment. In addition, the lack of enzyme inhibition in foods (even at high radiation doses required for commercial sterilization) following irradiation is a clear disadvantage (Korkmaz and Polat, 2005) since enzyme activity in post-harvest or post-slaughter foods is detrimental to food quality parameters such as flavor, color, aroma, texture and nutritional value, and therefore the activities of enzymes must be suppressed or eliminated in order to stabilize the food and prolong its storage life (Whitaker, 1991). On the other hand, cold plasma has been shown to inactivate a range of enzymes such as peroxidase, polyphenol oxidase, alkaline phosphatase and lysozyme, however some studies reported the opposite effect (unaltered or enhanced enzyme activity) (Misra et al., 2016). Furthermore, for widespread use of food irradiation, safety concerns like nuclear threats, radioactivity, genetic mutation and cancer as well as negative public perceptions about irradiated foods are the significant drawbacks (Korkmaz and Polat, 2005), whereas such apprehensions are minimal with nonthermal plasma technology.

Application of nonthermal plasma to reduce the microbial load of fresh produce has been reviewed recently (Pignata et al., 2017). It has been shown in the review that, on average, plasma treatments (DBD, corona discharge, MW, plasma jet, low pressure and other plasma process) can reduce microbial load (*E. coli* sp., *Salmonella* sp., *Listeria* sp., mesophilic bacteria, fungi, yeast, spores and bacilli and even other micro-organisms) on fresh produce by 2.73 ± 1.44 log. Corona discharges belong to one kind of nonthermal plasmas produced at atmospheric pressure.

In most studies, food samples artificially inoculated with different pathogens have been used to determine the decontamination efficacy of these emerging disinfecting agents (Al-Qadiri et al., 2016; Forghani and Oh, 2013; Luo et al., 2016). And, only few studies are conducted using naturally contaminated samples. Sometimes, the use of more than one disinfectant for produce decontamination would be beneficial in terms of microbial inactivation efficiency. Therefore, in the present study, the effectiveness of two advanced disinfectants, namely electrolyzed water

and nonthermal plasma, was tested for the decontamination of natural contaminants on collards.

Materials and methods

Fresh produce

Fresh collards were purchased from a local grocery store (K-mart, Dunchon-dong, Seoul, Korea).

Detection and enumeration of microbial contaminants

For about 3 g of the collards taken in a stomacher bag (3 M Microbiology, St. Paul, MN, USA), 27 mL of sterile saline (0.85% NaCl) solution was added. Later, the mixture was homogenized for 3 min using a paddle blender (IUL Instruments, Barcelona, Spain). Under aseptic conditions, 1-mL aliquots were removed from the stomacher bag filtrate, serially diluted (seven tenfold serial dilutions) in sterile saline, then plated in Petri dishes (pour plate method) containing melted agar culture media (general purpose non-selective or selective media) (~ 15 mL each), and finally incubated at 37 °C for 24–48 h.

General and selective growth media were used for the detection of microbial contaminants, and the standard plate count method was used to enumerate viable counts (KFDA, 2011). General-purpose media, namely plate count agar (PCA) (Difco, Becton–Dickinson and Co., Sparks, MD, USA) (composed (g/L) of pancreatic digest of casein 5.0, yeast extract 2.5, dextrose 1.0 and agar 15.0) for mesophilic aerobic bacteria and potato dextrose agar (PDA) (Difco, Becton–Dickinson and Co., Sparks, MD, USA) (composed (g/L) of potato starch (from infusion) 4.0, dextrose 20.0 and agar 15.0) for yeasts and mold, were used. A selective enrichment medium, namely eosin methylene blue agar, modified (Holt-Harris and Teague) (Difco, Becton–Dickinson and Co., Sparks, MD, USA), was used for the detection of coliforms and *E. coli*.

Electrolyzed water generation

A custom-built electrolyzed water generator (ENOGEN 40P, Dyeco, Seongnam, Korea) was used to produce electrolyzed water (EW) suitable for collards washing. Dimensions and working conditions of the system were the same as those described in our previous work (Puligundla et al., 2018). The average rates of brine inflow and catholyte outflow were 2.73 and 442 mL/min, respectively. Under these conditions, acidic electrolyzed water (AEW) containing 230 mg/L chlorine and having a pH of 3.66 was produced without any off-odor or pungent odor.

Collards treatment using AEW

Treatment was performed by soaking the collards in the AEW for different time periods (1, 3, 5, 7.5 and 10 min). During the treatment process, samples (approx. 3 g each) of the collards were taken into reusable stainless steel mesh tea ball strainers with chain to hold and washed for pre-determined time periods. Immediately following the treatment, the samples were rinsed with distilled water. Thereafter, they were tested for their microbial counts, physicochemical and sensory characteristics. The collards washed with distilled water (DW) were used as positive controls, and the unwashed samples served as negative controls.

Corona discharge plasma jet (CDPJ) generation

The plasma was generated using a high voltage (20 kV) direct current (DC) source, at 1.5 A current and 58 kHz frequency, as described in our previous studies (Kim et al., 2015; Puligundla et al., 2017).

Collards treatment using CDPJ

The collard greens were cut into 2 × 2 cm squared pieces and they were placed in Petri plates (3 g each) for the plasma treatment. A distance of 35 mm was maintained between the tip of the plasma electrode and the sample plate. The samples were treated using the plasma for pre-determined durations (30, 60, 90 and 120 s). Immediately after the treatment, microbial survival was determined according to the aforementioned procedure.

Total phenolic content

The total phenolic content of the collards was estimated by using Folin-Ciocalteu's phenol reagent, as described by Singleton and Rossi (1965).

Free radical scavenging activity

The free radical scavenging activity of the collards was measured according to the method of Blois (1958). The percent DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity was calculated using the following formula:

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

Ascorbic acid

The vitamin C content of the collards was estimated according to the AOAC official method 967.21 (AOAC, 2005).

Sensory evaluation

A panel containing untrained students (12) from the Department of Food Science and Biotechnology, Gachon University, was involved in the evaluation of sensory qualities of the collard greens. The negative controls, DW- and AEW-treated collard samples (60 samples per session) were presented to the evaluators' panel for scoring different quality properties, including appearance, color, and flavor. In addition, the overall acceptability scores of the collards were calculated as the mean of scores given for these parameters. A 9-point hedonic scale was used to determine the degree of liking, ranging from very poor to excellent (1 = dislike extremely, 9 = like extremely).

Statistical analysis

Results are shown as the mean ± standard deviation (SD) of three replicates. The SAS statistical software package (version 9.2, SAS Institute Inc., Cary, NC, USA) was used for performing statistical analyses. And, one-way ANOVA followed by Duncan's multiple range tests were used for analyzing the variance ($p < 0.05$) of the data.

Results and discussion

Microbial quality of collards

The collards were found to be contaminated with aerobic bacteria and yeasts and mold at significant levels. The mean ± standard deviation levels of the aerobic bacteria and yeasts and mold were 6.49 ± 0.07 and 6.37 ± 0.01 log CFU/g, respectively. Some of the samples contained coliforms below the detection limit of 2.18 log CFU/g. However, the common fresh produce contaminant, *E. coli*, was not detected from the samples. Vegetables are highly vulnerable to contamination by microorganisms, including pathogenic strains, due to the presence of favorable growth conditions, such as moisture content, pH, and texture. In a study, for all tested leafy greens and herbs, the geometric mean indicator levels of microorganisms ranged from 4.5 to 6.2 log CFU/g (aerobic bacteria); < 1–4.3 log CFU/g (coliforms and *Enterococcus*); and < 1–1.5 log CFU/g (*E. coli*). In that study, collard greens were shown to be contaminated with aerobic bacteria, *Enterococci*, total coliforms and *E. coli* at levels (log mean ± standard

deviation) of 4.5 ± 1.0 , 1.3 ± 0.6 , 1.0 ± 0.7 and 0.7 ± 0.0 , respectively (Johnston et al., 2005).

Inactivation of contaminants

Time-dependent reduction in the viable count of the microbial contaminants was noted following the AEW treatment or the plasma treatment or the combination of both treatments. Upon soaking/treating the collards using the AEW alone for 10 min, the initial counts of the aerobic bacteria and yeasts and mold were reduced by 2.20 and 2.09 log CFU/g, respectively. As shown in Fig. 1, a linear decrease in the viable count was observed with the increased AEW soaking time for up to 5 min. Thereafter, the rate of inactivation was drastically reduced for both the aerobic bacteria and yeasts and mold. On the other hand, DW treatment (positive control) did not exert any significant effect on the contaminants' viabilities. The microbial inactivation patterns similar to those obtained using the AEW were observed upon treatment using the CDPJ for 120 s; average reductions of 0.64 and 0.63 log CFU/g were noted for the aerobic bacteria and yeasts and mold, respectively.

The combination treatment using the AEW for 5 min followed by the CDPJ treatment for 1 min exerted an additive effect on inactivation, the aerobic bacteria and

yeasts and mold were inactivated by 2.22 and 1.77 log CFU/g (Fig. 2). The combination treatment significantly decreased the treatment time required to achieve similar levels of inactivation to that of the treatment with AEW alone for 10 min. On the other hand, the combination of DW and the CDPJ exerted insignificant inactivation effect (max. 0.49 log CFU/g reduction) on the contaminants.

In practical analytical food microbiology, the phenomenon of cell injury following the application of physical agents (heat, hydrostatic pressure, irradiation etc.) may present considerable problems. Different treatments related to food processing such as heating, chilling, drying, irradiation, freeze-thawing, and sanitizers may induce sublethal damage in cells or spores (Busta, 1976). The sublethally-damaged cells or injured cells are 'viable' but are not metabolic activity enough to achieve cell division. Subsequently, microbiological examination for quality control can indicate low plate counts, when in fact the sample contains a high number of injured cells (Forsythe, 2010). In validation of inactivation procedures, injured organisms are potentially as important as their normal counterparts since, in a favorable environment, injured cells can repair cellular damage and recover all their normal properties including virulence (this process termed as resuscitation) (Wu, 2008). Therefore, in ensuring the microbiological quality and safety of fresh-cut produce, the

Fig. 1 The inactivation patterns of the aerobic bacteria and yeasts and mold upon the acidic electrolyzed water and corona discharge plasma jet (CDPJ) treatments

Fig. 2 The inactivation patterns of the microbial contaminants of the collards by the combination treatment (AEW + CDPJ)

presence of sub-lethally-damaged microorganisms must be taken into account. In this study, the possibility of development of sub-lethally-damaged cells due to the AEW or CDPJ or AEW + CDPJ treatment cannot be ruled out. Since sub-lethally injured cells often fail to grow on selective media, the final coliform populations presented in the data (following the treatments) may not be representative of the total populations in the samples. However, the sub-lethally injured cells of the aerobic bacteria and yeasts and mold can grow along with non-injured cells on non-selective PCA and PDA media.

Microbiological safety of fresh produce cannot be achieved by washing with tap water alone (Issa-Zacharia et al., 2011). Therefore, effective sanitation is crucial before their consumption. Slightly acidic electrolyzed water (SAEW) has been used as novel sanitizer for fresh produce decontamination (Ding et al., 2015; Hao et al., 2011; Koide et al., 2011). In a study, on treating cherry tomatoes using SAEW and ultrasound (combined treatment), natural contaminants, namely total aerobic bacteria and yeasts and molds, were reduced by 1.77 log CFU/g and 1.50 log CFU/g, respectively (Ding et al., 2015).

A limited information is available on the mechanism of electrolyzed water-induced microbial inactivation. The

active chlorine species of electrolyzed water (Cl_2 , HOCl , and OCl^-) are known to induce microbial inactivation (Rahman et al., 2016). It has been shown that, apart from the active chlorine species, the reactive oxygen species (O_3 and H_2O_2) that generate during electrolysis can also contribute to the microbicidal action of electrolyzed water (Jeong et al., 2009).

Corona discharges generated in air have been shown to have strong antimicrobial activity (Puligundla et al., 2017). Corona plasma discharges generate chemically active species (oxygen ions and other charged species), and they act as strong oxidizers (Deng et al., 2007). Relatively high levels of inactivation by the combined treatment (AEW + CDPJ) in this study could be attributed to the additive effect of the chemically active species from both the disinfectants.

Effect on biochemical properties

Compared to negative controls, no significant ($p > 0.05$) changes in the levels of total phenolics were observed in the AEW-treated (up to 3 min) collards. However, a significant decrease was observed in the collards treated (AEW) for 5 min. On the contrary, the AEW treatment (1, 3 and 5 min) followed by the CDPJ treatment for 1 min had led to an increase in total phenolics content (Table 1). The increase was significant only in the samples treated using the AEW for 1 min followed by the CDPJ treatment for 1 min. Further treatment using the AEW (for 3 and 5 min) showed a negative effect on the levels of total phenolics. These results indicate that a prolonged treatment of collards using the AEW may exert a negative impact on their phenolic profiles. On the contrary, the CDPJ treatment appears to have a positive impact.

Compared to negative controls, the DPPH radical scavenging activity of the collards was insignificantly ($p > 0.05$) altered by either the AEW treatment alone or the combined AEW and CDPJ treatment. The averages of the DPPH radical scavenging activities of the collards were ranged between 52.14 and 54.26%.

A slight, but significant, decrease in ascorbic acid levels was noted in the collards upon the AEW treatment compared with negative controls. But the reduction was more significant upon the AEW treatment (1–5 min) followed by the CDPJ treatment (1 min). The average levels of ascorbic acid were ranged between 28.34 and 31.35 mg/100 g.

Effect on sensory properties

The sensory properties of the collards, namely appearance, color and flavor, were not significantly ($p > 0.05$) affected by either the AEW treatment alone or the combination of the AEW and CDPJ treatments when compared to negative

Table 1 Effects of the AEW treatment (alone and in combination with the CDPJ) on the biochemical properties of the collards

Treatment details	Biochemical properties		
	Total phenolics (mg GAE/g)	DPPH radical scavenging activity (%)	Ascorbic acid (mg/100 g)
AEW-0	13.54 ± 0.11 ^{ab}	52.54 ± 0.64 ^a	31.35 ± 0.72 ^a
AEW-1	13.88 ± 0.40 ^{ab}	52.84 ± 1.49 ^a	29.64 ± 1.96 ^{ab}
AEW-3	13.84 ± 0.61 ^{ab}	52.41 ± 0.80 ^a	31.34 ± 1.43 ^a
AEW-5	13.12 ± 0.62 ^{ab}	52.77 ± 2.17 ^a	29.22 ± 1.30 ^{ab}
AEW-1 + CDPJ	14.31 ± 1.06 ^a	54.26 ± 0.24 ^a	29.22 ± 1.30 ^{ab}
AEW-3 + CDPJ	13.98 ± 0.60 ^{ab}	52.33 ± 1.63 ^a	28.34 ± 2.00 ^b
AEW-5 + CDPJ	13.77 ± 0.20 ^{ab}	52.14 ± 0.80 ^a	29.66 ± 0.74 ^{ab}

GAE gallic acid equivalent; ^{a-b} means in the same column followed by different letters are significantly different ($p < 0.05$)

Table 2 Effects of the AEW treatment (alone and in combination with the CDPJ) on the sensory properties of the collards

Treatment details	Sensory properties			
	Appearance	Color	Flavor	Overall acceptance
AEW-0	7.250 ± 1.06 ^{a*}	7.167 ± 1.03 ^a	7.083 ± 0.99 ^a	7.083 ± 0.90 ^a
AEW-1	7.167 ± 0.94 ^a	7.000 ± 0.95 ^a	7.083 ± 0.99 ^a	7.083 ± 1.08 ^a
AEW-3	7.167 ± 0.72 ^a	7.167 ± 0.58 ^a	6.833 ± 0.39 ^a	6.917 ± 0.29 ^a
AEW-5	7.250 ± 1.06 ^a	7.000 ± 0.29 ^a	6.750 ± 1.14 ^a	6.750 ± 0.97 ^a
AEW-1 + CDPJ	6.917 ± 0.90 ^a	6.833 ± 0.94 ^a	6.500 ± 0.80 ^a	6.833 ± 0.94 ^a
AEW-3 + CDPJ	6.917 ± 0.90 ^a	6.750 ± 1.14 ^a	6.417 ± 0.90 ^a	6.833 ± 0.83 ^a
AEW-5 + CDPJ	6.917 ± 0.90 ^a	6.750 ± 1.06 ^a	6.500 ± 0.67 ^a	6.917 ± 0.90 ^a

*Means followed by the same letter in the column did not differ significantly from each other (all $p > 0.05$)

controls (Table 2). Collards treated with the AEW only exhibited relatively superior sensory properties compared to those treated with the AEW followed by the CDPJ. The overall acceptance of the collards was relatively unchanged upon the treatments, either using the AEW alone or the combination of the AEW and CDPJ, compared to negative controls. Similar results were obtained when AEW was used for broccoli sprout washing (Puligundla et al., 2018), indicating that AEW can readily be used for fresh produce decontamination purposes.

In conclusion, the initial counts of aerobic bacteria and yeasts and mold in the collards were 6.49 and 6.37 log CFU/g, respectively. AEW suitable for the collards sanitation was produced by optimizing the flow rates of brine and catholyte in the electrolyzed water generator. In the combination treatment, the optimal treatment times using the AEW and plasma were 5 min and 60 s, respectively. The combined effect of the AEW and CDPJ was more effective for the microbial reduction than the AEW treatment alone. Compared to negative controls, the AEW treatment alone or the combined AEW and CDPJ treatment did not affect negatively the tested sensory properties and DPPH radical scavenging activity of the collards; however,

the levels of the vitamin C and total phenolics were significantly altered.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

References

- Al-Qadiri HM, Al-Holy MA, Shiroodi SG, Ovissipour M, Govindan BN, Al-Alami N, Sablani SS, Rasco B. Effect of acidic electrolyzed water-induced bacterial inhibition and injury in live clam (*Venerupis philippinarum*) and mussel (*Mytilus edulis*). *Int. J. Food Microbiol.* 231: 48–53 (2016)
- AOAC. Official Method of Analysis of AOAC Intl. 18th ed. Method 967.21. Association of Official Analytical Chemists, Gaithersburg, MD, USA (2005)
- Blois MS. Antioxidant determination by the use of a stable free radical. *Nature* 181: 1199–1200 (1958)
- Busta FF. Practical implications of injured microorganisms in food. *J. Milk Food Technol.* 39: 138–145 (1976)

- Deng S, Ruan R, Mok CK, Huang G, Lin X, Chen P. Inactivation of *Escherichia coli* on almonds using nonthermal plasma. *J. Food Sci.* 72: M62–M66 (2007)
- Ding T, Ge Z, Shi J, Xu YT, Jones CL, Liu DH. Impact of slightly acidic electrolyzed water (SAEW) and ultrasound on microbial loads and quality of fresh fruits. *LWT - Food Sci. Technol.* 60(Part 2): 1195–1199 (2015)
- Fan X, Niemira BA, Sokorai KJB. Sensorial, nutritional and microbiological quality of fresh cilantro leaves as influenced by ionizing radiation and storage. *Food Res. Int.* 36: 713–719 (2003)
- Food and Agriculture Organization (FAO)/World Health Organization (WHO). Microbiological risk assessment series: Microbiological hazards in fresh fruit and vegetables (2008). Available at <http://www.who.int/foodsafety>
- Forghani F, Oh DH. Hurdle enhancement of slightly acidic electrolyzed water antimicrobial efficacy on Chinese cabbage, lettuce, sesame leaf and spinach using ultrasonication and water wash. *Food Microbiol.* 36: 40–45 (2013)
- Forsythe SJ. Methods of detection and characterization. 2nd ed., pp. 224–265. In: *The Microbiology of Safe Food*. Forsythe SJ (ed). John Wiley and Sons, Inc., New York, USA (2010)
- Hao JX, Liu HJ, Liu R, Dalai WY, Zhao RP, Chen TP, Li L. Efficacy of slightly acidic electrolyzed water (SAEW) for reducing microbial contamination on fresh-cut cilantro. *J. Food Safety* 31: 28–34 (2011)
- Ignarro LJ, Balestrieri ML, Napoli C. Nutrition, physical activity, and cardiovascular disease: an update. *Cardiovasc. Res.* 73 (2): 326–340 (2007)
- Issa-Zacharia A, Kamitani Y, Miwa N, Muhimbula H, Iwasaki K. 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 (2011)
- Jeong J, Kim C, Yoon J. The effect of electrode material on the generation of oxidants and microbial inactivation in the electrochemical disinfection processes. *Water Res.* 43: 895–901 (2009)
- Johnston LM, Jaykus LA, Moll D, Martinez MC, Anciso J, Mora B, Moe CL. A field study of the microbiological quality of fresh produce. *J. Food Protect.* 68: 1840–1847 (2005)
- KFDA. Korean food standards codex (Vol. 2). Chungbuk, Korea: Korea Food and Drug Administration, 9.3.1.1–9.3.18.2 (2011)
- Kim JW, Puligundla P, Mok C. Microbial decontamination of dried laver using corona discharge plasma jet (CDPJ). *J. Food Eng.* 161: 24–32 (2015)
- Koide S, Shitanda D, Note M, Cao W. Effects of mildly heated, slightly acidic electrolyzed water on the disinfection and physicochemical properties of sliced carrot. *Food Control* 22: 452–456 (2011)
- Korkmaz M, Polat M. Irradiation of fresh fruit and vegetables. pp. 387–428. In: *Improving the safety of fresh fruit and vegetables*. Jongen W (ed). Woodhead Publishing Limited, Cambridge, England (2005)
- Luo K, Kim SY, Wang J, Oh DH. A combined hurdle approach of slightly acidic electrolyzed water simultaneous with ultrasound to inactivate *Bacillus cereus* on potato. *LWT - Food Sci. Technol.* 73: 615–621 (2016)
- Maffei DF, de Arruda Silveira NF, Catanozi MPLM. Microbiological quality of organic and conventional vegetables sold in Brazil. *Food Control* 29: 226–230 (2013)
- Misra NN, Pankaj SK, Segat A, Ishikawa K. Cold plasma interactions with enzymes in foods and model systems. *Trends Food Sci. Technol.* 55: 39–47 (2016)
- Monnin A, Lee J, Pascall MA. Efficacy of neutral electrolyzed water for sanitization of cutting boards used in the preparation of foods. *J. Food Eng.* 110: 541–546 (2012)
- Parish ME, Beuchat LR, Suslow TV, Harris LJ, Garret EH, Farber JM, Busta FF. Methods to reduce/eliminate pathogens from fresh and fresh-cut produce. *Compr. Rev. Food Sci. F.* 2(Suppl): 161–178 (2003)
- Pignata C, D'Angelo D, Fea E, Gill G. A review on microbiological decontamination of fresh produce with nonthermal plasma. *J. Appl. Microbiol.* 122: 1438–1455 (2017)
- Puligundla P, Kim JW, Mok C. Broccoli sprout washing with electrolyzed water: Effects on microbiological and physicochemical characteristics. *LWT - Food Sci. Technol.* 92: 600–606 (2018)
- Puligundla P, Kim JW, Mok C. Effect of corona discharge plasma jet treatment on decontamination and sprouting of rapeseed (*Brassica napus* L.) seeds. *Food Control* 71: 376–382 (2017)
- 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. F.* 15: 471–490.
- Singleton VL, Rossi JA. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *Am. J. Enol. Viticult.* 16: 144–158 (1965)
- Van Haute S, Samperis I, Holvoet K, Uyttendaele M. Physicochemical quality and chemical safety of chlorine as a reconditioning agent and wash water disinfectant for fresh-cut lettuce washing. *Appl. Environ. Microbiol.* 79: 2850–2861 (2013)
- Whitaker JR. Enzymes: monitors of food stability and quality. *Trends Food Sci. Technol.* 2: 94–97 (1991)
- Wu VCH. A review of microbial injury and recovery methods in food. *Food Microbiol.* 25: 735–744 (2008).