



Microbial Decontamination of Mung Bean Sprouts Using Electrolyzed Water and Its Effects on The Physicochemical and Sensory Properties of The Sprouts

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ABSTRACT

Electrolyzed water (EW) was used to decrease the levels of microbial contaminants in commercial mung bean sprouts. High contamination levels of aerobic bacteria as well as yeasts and mold were observed in raw mung bean sprouts (on average 7.67 ± 0.22 and 7.70 ± 0.07 log CFU/g, respectively). Mung bean sprouts were treated with EW produced at varying flow rates of brine and deionized water streams. Acidic electrolyzed water (AEW) with a pH of 3.66 and a chlorine concentration of 230 mg/L exhibited the best performance in reducing the contaminant levels. Compared to untreated or tap water (TW)-treated sprouts, sensory qualities (appearance, color, and flavor) of AEW-treated mung bean sprouts were not significantly different ($P > 0.05$) for up to cumulative treatment time of 40 s. In addition, no significant ($P > 0.05$) alterations were observed in the levels of moisture content, reducing sugars content, and total phenolic contents of mung bean sprouts by AEW treatment during the same period. On the other hand, the 2,2-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity of the sprouts was significantly improved following AEW treatment. In addition, compared with untreated or TW-treated samples, an improved shelf life was noted for AEW-treated (cumulative submerged time: 40 s) mung bean sprouts during storage at 4 and 25 °C. The research results can be applied to design AEW-based mung bean sprout sanitation system.

Keywords: mung bean sprouts, electrolyzed water, microbial inactivation, functional quality, sensory quality

1. INTRODUCTION

Seed sprouts are an inexpensive source of nutrients essential to human life, especially they are rich in vitamins, proteins, and minerals. Further, they contain phytochemicals such as phenolics and glucosinolates, amino acids, and enzymes [1]. Raw seed sprouts of soybeans, alfalfa, mung bean, broccoli, and radish are popularly consumed (healthy foods consumers) on sandwiches, wraps,

and salads [2]. Nevertheless, sprouts have the potential to harbor pathogenic bacteria and fungi [3], and many foodborne illness outbreaks have been shown to be associated with the consumption of pathogen-contaminated sprouts [4].

There are different approaches to do decontamination of sprouts. The USDA has recommended chlorinated water (20000 mg/L

chlorine solution) treatment of seeds prior to sprouting in order to ensure microbial safety [4]. However, a limited success has been achieved using this method in terms of the reduction of pathogens since microorganisms can reestablish at any stage during the growth of sprouts [5]. Additional disadvantages associated with using chlorinated water for fresh produce sanitization include relatively low inactivation efficiency, the initiation of resistance in microorganisms, and the formation of carcinogenic by-products [6]. As a result, chemical-free and environmentally friendly methods for sanitizing fresh produce have steadily been gaining prominence.

Gamma rays have successfully been used to decrease bacterial pathogen load in broccoli seeds and sprouts [7]. On using ionizing radiation, total aerobic plate count on cilantro was decreased by up to 3 log CFU/g without negatively affecting its shelf life and sensorial quality [8].

In recent years, the application of electrolyzed water (EW) for fresh produce decontamination is increasingly gaining significance. It is a safe alternative to traditional chlorinated sanitizers like sodium hypochlorite, which is known to irritate mucous membrane and skin, and cause toxicity [9]. Acidic EW (AEW) and neutral EW (NEW) as novel sanitizers have been proposed for use in the food industry [10, 11]. It has been shown that, upon treatment (10 min) with mildly heated AEW (45 °C, pH 5.5), total aerobic bacteria as well as molds and yeasts on sliced carrot were inactivated by 2.2 and $>1.9 \log_{10}$ CFU/g, respectively, when compared with tap water treatment [12]. EW is more environmentally friendly compared to chlorinated sanitizers since it readily converts to regular water upon dilution with tap water and on contact with organic matter [13].

Fresh produce sanitization with EW has been largely studied, however, most studies were performed using artificially inoculated produce samples [14-19], and only a few studies [12, 20] have reported the inactivation of natural

contaminating microbes in produce samples. So, in this study, we evaluated the potential of EW for the inactivation of naturally occurring microbial contaminants of commercial mung bean sprouts. In addition, the possible impact of EW treatment on the physicochemical and sensory properties of the sprouts was studied.

2. MATERIALS AND METHODS

2.1 Sprout Samples

Full-grown raw mung bean sprouts packed in plastic packaging bags were procured from a local grocery store in Seongnam-si, Korea. The sprouts were stored at 4 °C until use. EW treatment of the sprouts was performed within 48 h after procurement.

2.2 Generation of Electrolyzed Water

EW for the treatment of mung bean sprouts were produced using an electrolyzed water system (model ENOGEN 40P, Dyeco, Seongnam, Korea). The dimensions of various components of the unit and operating conditions have been discussed in the previous study [5]. Briefly, in the process of EW generation, pipe flows of saturated aqueous NaCl solution (brine, approx. 26 wt.% NaCl) and deionized water were continuously fed into the system. Following the electrolysis of these solutions, two distinct products were formed, namely anolyte (pH ~2-3) and catholyte (pH ~11-12) solutions. The flow rates of brine (range: 2.5 to 10 mL/min) and deionized water (range: 340 to 360 mL/min) were optimized in order to generate acidic electrolyzed water (AEW) appropriate for sprout sanitation purposes. The pH and free chlorine concentration of AEW were determined using a Mettler Toledo 320 pH meter (Mettler Toledo Instruments, USA) and a portable photometer (model HI 95711, Hanna Instruments, Woonsocket, RI, USA), respectively. In addition, the salinity of AEW was analyzed using a salinity tester (model SB1500pro, HM Digital, Seoul, Korea).

2.3 AEW Treatment for Sprout Decontamination

Mung bean sprouts were taken (1.0 ± 0.05 g each time) into a stainless steel mesh tea ball or infuser strainer with a chain to hold and treated by dipping them in AEW for predetermined durations. The dipping was performed in intermittent mode (i.e., submerging in AEW for 2 s followed by draining for 2 s). Cumulative submerged time was maintained in the range of 0 to 60 s. After that, mung bean sprouts were subjected to residual microbial analysis as well as physicochemical and sensory characterization. As positive controls, tap water (TW)-treated mung bean sprouts were used, and untreated sprouts were used as negative controls. TW treatment was conducted for 20 s in a similar manner as for the AEW treatment described above.

2.4 Contaminants Detection and Estimation of Residual Microbial Counts

Microbial contaminants that existed naturally in mung bean sprouts were detected using general-purpose as well as selective enrichment media. All microbial culture media used in this study were procured from Becton Dickinson and Company (Sparks, MD, USA). Total viable counts of contaminants were quantified according to the standard plate count (SPC) method [21]. Mung bean sprouts (1 g each) were taken into filter stomacher bags (3M Korea, Seoul) and sterile 0.85 % NaCl solution (9 mL) was added to each bag. Subsequently, the bagged samples were homogenized for 3 min using a paddle blender (Masticator, IUL Instruments, Barcelona, Spain) at 8.0 strokes/s. Thereafter, under aseptic conditions, aliquots of 1.0 mL of each sample were removed from the bag filtrates, serially diluted in 0.85 % sterile saline, and then plated in 90 mm diameter Petri plates (pour plate method) containing either general-purpose or selective agar media. Finally, the plates were allowed to incubate at 37 °C for 24-48 h. Plate count agar and potato dextrose agar (both were general purpose media) were used to determine the counts of aerobic bacteria as well as yeasts

and molds, respectively. Selective enrichment media, namely, mannitol-egg yolk-polymyxin agar, eosin-methylene blue agar, Baird-Parker agar and xylose-lysine-deoxycholate agar were used to detect *Bacillus cereus*, *Escherichia coli*, *Staphylococcus aureus*, and *Salmonella* spp., respectively. Following AEW treatment, 1 g mung bean sprouts from each treatment condition were taken and placed in individual stomacher bags and sterile 0.85 % saline was added (9 mL to each bag). Thereafter, the samples were homogenized for 3 min and viable residual microbial counts in the filtrates were determined according to the aforementioned procedure.

2.5 Modeling of Inactivation

The first-order inactivation model was generally employed to explain survivor curves of microorganisms treated with lethal agents, assuming a linear logarithmic decrease in survivors counts over the treatment period, as given in Eq. (1).

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

where, N_0 and N are the initial and final microbial counts, respectively; t is exposure time (min), and k is inactivation rate constant.

The above equation was valid only for log-linear inactivation curves. The majority of inactivation curves, however, were known to exhibit non-log-linear relationship. In such circumstances, the application of pseudo-first-order kinetics, especially Singh and Heldman model [22] was suggested [23]. This proposed model can be described by using Eq. (2), and was modified as shown in Eq. (3). Using $\log(t)$ vs $\log[\log(N_0/N)]$, the intercept and slope of the regression line were obtained and the D -like value (D' -value) was calculated.

$$\log \frac{N_0}{N} = \left[\frac{t}{D'} \right]^n \quad (2)$$

$$\log \left[\log \left(\frac{N_0}{N} \right) \right] = n \log(t) - n \log(D') \quad (3)$$

Where D' is D -like value (min) similar to the decimal reduction time n is curve shape factor.

2.6 Preparation of Sprout Extract for Chemical Analysis

Sprout extract was prepared as previously described [5]. Briefly, samples (untreated, TW-and AEW-treated) of mung bean sprouts (10 ± 0.3 g each) were milled for 3 min using a blender (HR2860, Philips, Korea), followed by freeze-drying for 24 h using a lyophilizer (Ilshin Lab Corporation, Yangju, Korea). The freeze-dried samples were extracted at room temperature (30 °C) with a mixture of distilled water, methanol, and 5N HCl (26:50:24 ratio) for 2 h. Both methanol and HCl were procured from Samchun Pure Chemical Co., Ltd., Korea. Thereafter, the extracts obtained were subjected to centrifugation (model DM0412, Scilogex, USA) at $2500 \times g$ at 4 °C for 10 min to remove undissolved material. The extraction step was repeated for two more times, and the resulting supernatants were combined and stored at 4 °C until used for biochemical analysis.

2.7 Estimation of Physicochemical Properties

The moisture content of mung bean sprouts was estimated by the AOAC method 934.06 [24].

Total phenolic contents of extracts from mung bean sprouts was estimated by using Folin-Ciocalteu reagent as previously described [25]. Values are expressed as mg gallic acid equivalents (GAE)/g dry weight. Standard curve for gallic acid was shown in supplementary Figure 1.

The dinitrosalicylic acid (DNS) method [26] was used to estimate reducing sugars in extracts from mung bean sprouts.

DPPH (2,2-diphenyl-2-picrylhydrazyl) radical scavenging activity of extracts from mung bean sprouts was determined according to the method of Blois [27] using the following formula:

Scavenging activity (%)

$$= \left(\frac{A_{517} \text{ of control} - A_{517} \text{ of sample}}{A_{517} \text{ of control}} \right) \times 100 \quad (4)$$

2.8 Sensory Evaluation

During the sensory evaluation, the samples of untreated, TW-treated, and AEW-treated mung bean

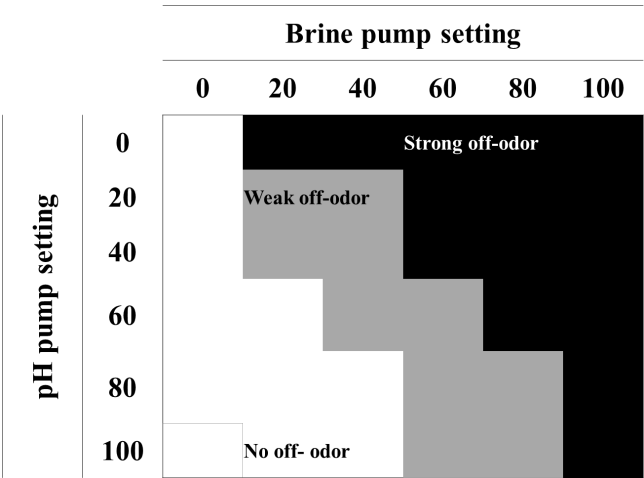


Figure 1. Off-odor (chlorine-like) levels in produced electrolyzed water at different pH and brine pump settings.

sprouts were presented to a panel of untrained students (12) from the Department of Food Science & Biotechnology, Gachon University, for scoring various quality characteristics, including appearance, color, and flavor. The overall acceptability of the sprouts was estimated as the average of scores given for these properties. The degree of liking or dislike was determined using a nine-point hedonic scale (9 = like very much, 5 = rejection point, 1 = dislike very much).

2.9 Storage Quality of Sprouts

Samples (10 g each) of mung bean sprouts (untreated, 20 s TW- and 40 s AEW-treated) were taken into 20cm × 14.9cm × 4.7cm dimension polyethylene bags (Ziploc, SC Johnson & Son, Inc., Racine, WI, USA), and incubated at 4 and 25 °C. Total contaminants counts were estimated periodically (once in every 3 h at 25 °C and once in every 24 h at 4 °C).

2.10 Statistical Analysis

Results were presented as the mean values ± standard deviation (SD) of three replicate experiments. The software package SAS 9.2 (SAS Institute Inc., Cary, NC) was used for performing statistical analyses. Statistical significance ($P < 0.05$) was determined by one-way ANOVA followed by the Duncan's multiple range test.

3. RESULTS AND DISCUSSION

3.1 Sprout Contaminants

Aerobic bacteria as well as yeasts and mold were found as contaminants in commercial mung bean sprouts. Their levels were relatively high, the average levels of total aerobic bacteria as well as yeasts and mold were 7.67 ± 0.22 and 7.70 ± 0.07 log CFU/g, respectively. However, common sprout-contaminating pathogenic microorganisms, including *Escherichia coli*, *Bacillus cereus*, *Staphylococcus aureus*, and *Salmonella* spp., were not detected from the tested samples. In a previous study, commercial fresh sprouts (mung bean, pak choi, kale, red radish, soybean, turnip rape, radish, red

cabbage, alfalfa, brassica, broccoli, buckwheat, Chinese cabbage, and tatsoi) have been shown to be contaminated with microbial contaminants at an unacceptable level, in addition to the potential pathogen (*Listeria monocytogenes*) in some samples (red radish, alfalfa and broccoli sprouts). In that study, mung bean sprouts from different sprout companies in Korea were shown to contain a total plate count of 1.2×10^7 CFU/g and a coliform count of 4.1×10^4 CFU/g; however, mung bean sprouts did not contain *L. monocytogenes* [28]. Due to intrinsic microflora of seeds as well as favorable environmental conditions during sprout growth, fresh sprouts usually possess total plate counts as high as 10^8 – 10^9 CFU/g [29, 30]. Elevated levels of contaminants in sprouts could also be due to unsanitary sprouting conditions and poor hygienic practices of producers and retailers [30].

3.2 Production of EW Suitable for Sprout Sanitation

The flow rates of brine as well as deionized water were varied to produce EW suitable for mung bean sprout sanitation. In EW generator, catholyte and anolyte solutions were allowed to mix in different proportions to generate acidic electrolyzed waters (AEW) having a pH range of 1.8 - 6.6. The flow rates of brine and deionized water were adjusted in such a way to obtain AEW with no disagreeable odor. AEWs produced at brine pump settings of 20 and 40 and at pH pump settings of 60, 80, and 100 exhibited no disagreeable odor (intensity was perceived through human nose), as shown in Fig. 1. Based on results of microbial inactivation potential of AEWs generated under the above-stated conditions, effective AEW for the mung bean sprout sanitation was chosen. AEW generated at brine pump setting of 20 and pH pump setting of 60 had exhibited the highest inactivation rate (Supplementary Figure 2), and therefore it was used solely as sanitizer in the present study for sprout decontamination. Under this condition, brine inflow and catholyte outflow rates were 2.73 ± 0.06 and 442 ± 7.64

mL/min, respectively; and the generated AEW exhibited no off-odor, 230 mg/L of chlorine, 0.23% salinity, and a pH of 3.66.

The pH, salinity, and chlorine levels of AEW generated at brine pump setting of 20 and pH pump setting of 80 were 4.26, 0.18% and 250 mg/L, respectively; and at brine pump setting of 40 and pH pump setting of 80 were 3.45, 0.26% and 490 mg/L, respectively. However, these AEWs were not used for the sprout treatment in this study due to relatively low inactivation efficiencies. The antimicrobial efficacy of EW was greatly influenced by concentration of chlorine (Cl_2 , ^-OCl and HOCl), oxidation-reduction potential (ORP), and pH [31]. The pH of EW plays an important role in the formation of various chlorine species. However, it has been reported that AEWs with wide pH range (2.6 to 7.0) and with adequate free chlorine (>2 mg/L) were highly effective against foodborne pathogenic bacteria, namely *L. monocytogenes* and *E. coli* O157:H7 [32].

3.3 Sprout Treatment Using AEW

Compared with untreated mung bean sprouts, as high as 1.81 ± 0.29 log CFU/g reduction of initial counts was noted for aerobic bacteria upon AEW treatment for 60 s (cumulative submerged time) (Figure 2a), whereas yeasts and mold were decreased by 2.03 ± 0.21 log CFU/g at the same treatment period (Figure 2b). On the other hand, in mung bean sprouts treated with TW (pH: 7.8 ± 0.1 , chlorine: 9 ± 1 mg/L), 0.73 and 0.80 log CFU/g reductions of aerobic bacteria as well as yeasts and mold were noted at the same treatment duration, respectively.

In a previous study, upon the application of slightly acidic electrolyzed water (SAEW, pH approx. 6.4, available chlorine concentration approx. 34 mg/L) for sanitizing cherry tomatoes, total aerobic bacteria as well as yeasts and mold were decreased by 1.45 and 1.10 log CFU/g, respectively; and in strawberries, 0.93 and 0.96 log CFU/g reductions in total aerobic bacteria as well as yeasts and mold were noted following

the SAEW treatment, respectively [20]. In another study, a significant reduction in the viable counts of natural microflora on fresh-cut cilantro was noted following SAEW treatment; reductions as high as 1.08, 1.56, and 1.64 log CFU/g were noted for coli-forming bacteria, total aerobic bacteria, as well as yeasts and mold following the treatment for 5 min, respectively [15]. Relatively higher microbial inactivation in the present study compared with the previous works could be due to variations in treatment-related factors, including but not limited to the type of material under treatment and treatment conditions in addition to EW characteristics such as pH, chlorine, ORP, temperature, etc.

Regarding the mechanism of microbicidal action of EW, active chlorine species (e.g., Cl_2 , HOCl , ^-OCl , etc.) are known to contribute to microbial cell inactivation [32]. In addition to chlorine species, oxidants such as reactive oxygen species (especially O_3 and H_2O_2) formed during electrolysis have been shown to contribute to the microbicidal efficiency of EW [33]. Low pH of AEW suppresses bacterial growth and it even makes microbes more vulnerable to dynamic chlorine [32].

3.4 Contaminants Inactivation Modeling and D' -value

Inactivation models are crucial for the assessment of quantitative risk. During the earlier stages of AEW treatment, the rates of inactivation of aerobic bacteria as well as yeasts and mold were exponentially increased with increasing treatment time (Figure 2a and 2b). However, gentler slopes were noted in the later stages of the treatment, indicating a decreased rate of inactivation. The first-order inactivation model was unsuccessful in explaining the kinetics of the inactivation over the entire treatment period. The values of the coefficients of determination (R^2) for the derived curves (using first-order kinetics) for aerobic bacteria as well as yeasts and mold were 0.897 and 0.955, respectively (Supplementary Figure 3).

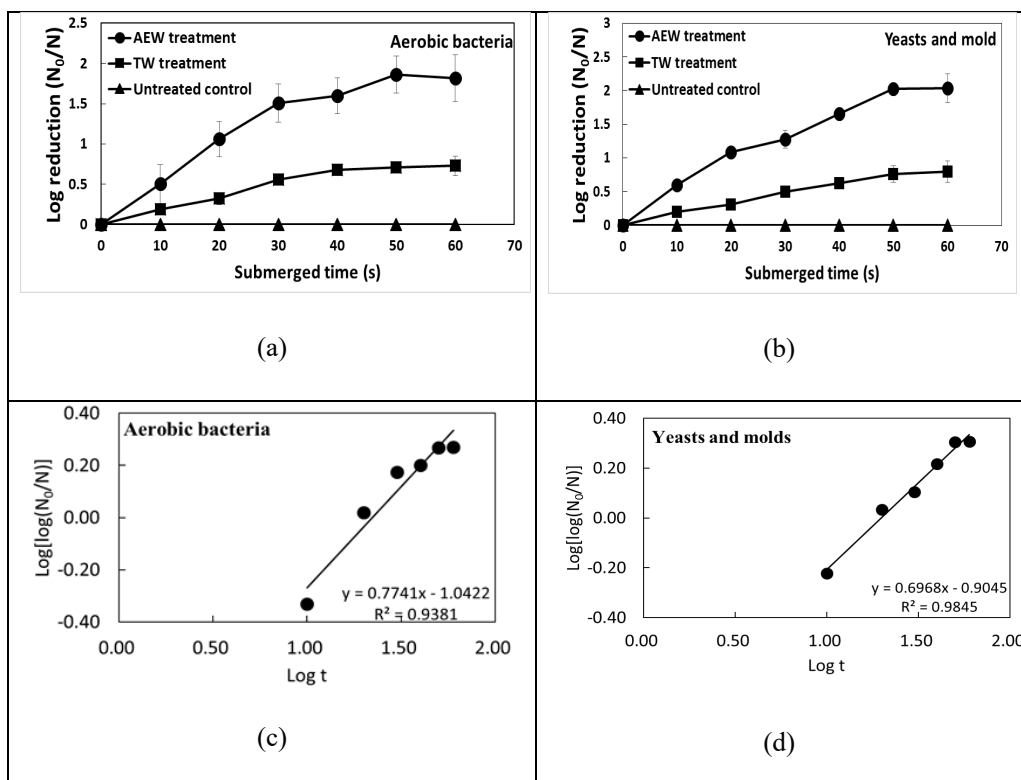


Figure 2. Inactivation effect of AEW on aerobic bacteria (a) and yeasts and mold (b) contaminants. Inactivation data fitted by the Singh-Heldman model (c) and (d).

Consequently, a pseudo-first-order inactivation kinetic model, also known as Singh-Heldman model was used. This kinetic model was found to fit the inactivation data well (Figure 2c and 2d). The value of R^2 closer to 1 implied that the AEW-induced inactivation patterns of the contaminant microbes in the mung bean sprouts could be better explained using the Singh-Heldman model.

D' -value calculated in this study was similar to decimal reduction time (D value) as in the case of heat sterilization (if $n = 1$), which refers to time required at a certain temperature to kill 90% of the organisms being studied [23]. Therefore, D' -value was a measure of microbial resistance to AEW-induced inactivation. Yeasts and mold (D' -value: 19.80 s cumulative submerged time) were inactivated at a slightly faster rate compared

with aerobic bacteria. Aerobic bacteria of the sprouts seemed to be somewhat more resistant to AEW-induced inactivation as their D' -value was relatively high (22.15 s cumulative submerged time).

3.5 Sensory Evaluation

Compared with untreated controls, sensory characteristics (appearance and flavor) of AEW-treated (up to a cumulative submerged time of 40 s) mung bean sprouts were significantly ($P < 0.05$) increased (Table 1); AEW-treated sprouts appeared relatively brighter, fresher and not displayed any unpleasant flavor. In addition, surface color of sprouts remained unaltered. However, upon further increase to cumulative submerged time of 60 s, a significant reduction

Table 1. Sensory scores* of mung bean sprouts untreated and treated with tap water (TW) and acidic electrolyzed water (AEW) for different submerged periods.

Sensory properties	Cumulative submerged time (s)				
	Untreated control	20 (TW)	20 (AEW)	40 (AEW)	60 (AEW)
Appearance	5.00 ± 0.77 ^{ab}	4.82 ± 0.98 ^{ab}	5.00 ± 1.00 ^a	5.55 ± 1.04 ^a	4.36 ± 0.67 ^b
Color	5.00 ± 1.18 ^a	5.20 ± 0.79 ^a	4.80 ± 1.23 ^a	5.09 ± 0.70 ^a	4.73 ± 0.47 ^a
Flavor	4.80 ± 1.14 ^{ab}	5.27 ± 1.10 ^a	5.00 ± 1.10 ^{ab}	5.30 ± 0.67 ^a	4.40 ± 0.70 ^b
Overall acceptance	5.36 ± 0.67 ^a	5.00 ± 0.67 ^{ab}	5.09 ± 0.83 ^a	5.55 ± 0.52 ^a	4.64 ± 0.50 ^b

*Judged by 12 panelists using 9-point hedonic scale.
 Values with same letters within same row are not significantly different ($P > 0.05$).

in all tested sensory characteristics, except color, was noted when compared with AEW-treated sprout samples for a cumulative submerged time of 40 s. The overall acceptance was significantly different between 60 s AEW-treated sprouts and other treatments, including 40 s AEW-treated or 20 s TW-treated or untreated sprouts. AEW-treated (cumulative submerged time: 40 s) mung bean sprouts appeared quiet firmer, crispy, and appetizing texture compared with those treated for cumulative submerged time of 60 s.

3.6 Physicochemical Properties

Compared to untreated control sprouts, no significant ($P > 0.05$) changes in moisture content, reducing sugars content, and total phenolic contents of mung bean sprouts were noted upon treatment (cumulative submerged time of up to 40 s) using AEW (Table 2). However, a significant increase of DPPH radical scavenging activity was noted following AEW treatment. AEW treatment of the sprouts for 60 s significantly increased the sprout moisture levels and significantly decreased the total phenolic content, while the sprout reducing sugar content was remained unaltered compared to the untreated control. The average levels of moisture were in the range of 90.46-93.10% (the highest value: 94.17%). The average levels of reducing sugars were in the range of 3.75-4.04 mg/g dry weight (the highest value: 4.5 mg/g dw). The

average levels of total phenolic contents ranged between 4.34-4.53 mg GAE/g dry weight (the highest value: 4.62 mg GAE/g dw). The average levels of DPPH radical scavenging activity ranged between 86.62-87.59% (the highest value: 88.04%). Slightly different results were obtained when broccoli sprouts were washed with AEW for 0 to 60 s; the levels of moisture and DPPH radical scavenging activity were increased and the levels of total phenolics content and reducing sugar were decreased, but not significantly, following AEW treatment [5].

3.7. Microbiological Quality of Mung Bean Sprouts During Storage at Different Temperatures

During storage at a temperature of 25 °C, initial differences of 1.0-1.5 log CFU/g in the counts of the contaminants between untreated control/ TW-treated and AEW-treated mung bean sprouts was maintained up to 6 h after the commencement of storage test as shown in Figure 3a. Thereafter, the difference in the microbial counts between the treatments was narrowed. As room temperature (25 °C) favors the growth of mesophilic aerobic bacteria as well as yeasts and mold [34], the counts of the contaminants at 15 h storage reached beyond 9 log CFU/g; which is generally consider as saturation level [35]. However, during storage at 4 °C, counts beyond 9 log CFU/g was

Table 2. Physicochemical characteristics of mung bean sprouts untreated and treated with tap water (TW) and acidic electrolyzed water (AEW).

Cumulative submerged time (s)	Physicochemical properties			
	Moisture content (%)	Reducing sugar contents (mg/g dw)	Total phenolic contents (mg GAE/g dw)	DPPH radical scavenging activity (%)
Untreated control	90.46 ± 0.50 ^b	3.82 ± 0.61 ^a	4.51 ± 0.15 ^{ab}	86.62 ± 0.26 ^b
20 (TW)	90.88 ± 0.35 ^b	3.75 ± 0.21 ^a	4.53 ± 0.03 ^a	86.66 ± 0.63 ^b
20 (AEW)	90.87 ± 0.68 ^b	3.79 ± 0.53 ^a	4.42 ± 0.06 ^{ab}	87.07 ± 0.23 ^{ab}
40 (AEW)	91.54 ± 0.40 ^b	4.04 ± 0.27 ^a	4.35 ± 0.12 ^{ab}	87.59 ± 0.40 ^a
60 (AEW)	93.10 ± 1.09 ^a	3.89 ± 0.33 ^a	4.34 ± 0.06 ^b	87.50 ± 0.44 ^a

Mean values with different lowercase letters within a column are significantly different ($P < 0.05$).

GAE, gallic acid equivalents; dw, dry weight.

observed after 4 days of storage (in the case of AEW-treated sprouts) and after 3 days of storage (in the case of untreated/TW-treated sprouts) (Figure 3b). Since the AEW treatment can only inhibit contaminants in mung bean sprouts for 15 h at 25 °C, the packaging of the sprouts under modified atmosphere conditions (especially at high CO₂ and low O₂ levels) following the AEW treatment could further extend their shelf life. In a previous study, it has been shown that, under modified atmosphere packaging (MAP, O₂: CO₂

was 2-4%: 11-15%) conditions, the shelf life of mung bean sprouts was extended up to 7 days at 0 °C and 24-48 h at 30 ± 2 °C [36].

4. CONCLUSIONS

The mean levels of mesophilic aerobic bacteria, and yeasts and mold contaminants in commercial mung bean sprouts were 7.67 ± 0.22 and 7.70 ± 0.07 log CFU/g, respectively. AEW suitable for the sanitation (pH 3.6, Cl₂ content of 230 mg/L) of mung bean sprouts was generated

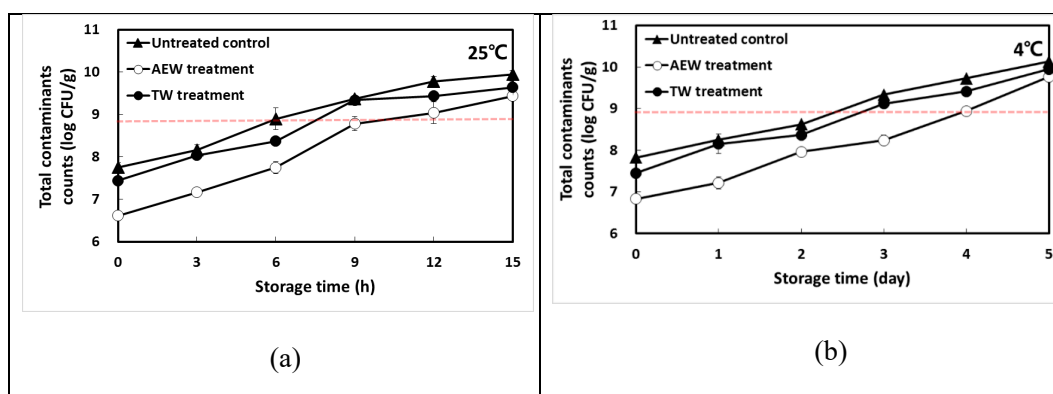


Figure 3. Changes in the levels of the mung bean sprout contaminants during 25 °C and 4 °C storage.

through the optimization of flow rates of brine and deionized water in EW generator. Over 90% (>1.5 log CFU/g) reductions in the initial counts of the detected microbial contaminants were achieved by AEW treatment for a brief period of 40 s (cumulative submerged time). The Singh-Heldman model was fitted well to the inactivation data. Sensory characteristics of mung bean sprouts were positively affected by AEW treatment for 40 s; AEW-treated sprouts appeared relatively fresh and brighter without any discoloration. In addition, a significant improvement in DPPH radical scavenging activity of the sprouts was noted in the same treatment duration. During storage at 4 °C, an improved shelf life was noted for AEW-treated (cumulative submerged time: 40 s) mung bean sprouts; however, the treatment effect on shelf life was limited at 25 °C. In conclusion, AEW having a pH value of 3.6 and 230 mg/L chlorine has the potential to improve the microbiological quality of raw mung bean sprouts, without negatively affecting their physicochemical and sensory properties, when treatment period doesn't exceed 40 s cumulative submerged time.

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