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Effects of a Pre-Filter and Electrolysis Systems on the Reuse of Brine in the Chinese Cabbage Salting Process

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ABSTRACT: In this study, the effects of a pre-filter system and electrolysis system on the safe and efficient reuse of brine in the cabbage salting process were investigated. First, sediment filter-electrolyzed brine (SF-EB) was selected as brine for reuse. Then, we evaluated the quality and microbiological properties of SF-EB and Chinese cabbage salted with SF-EB. The salinity (9.4%) and pH (4.63) of SF-EB were similar to those of control brine (CB). SF-EB turbidity was decreased (from 0.112 to 0.062) and SF-EB residual chlorine (15.86 ppm) was higher than CB residual chlorine (0.31 ppm), and bacteria were not detected. Salinity (2.0%), pH (6.21), residual chlorine (0.39 ppm), chromaticity, hardness, and chewiness of cabbage salted with SF-EB were similar to those of cabbage salted with CB. The total bacterial count in cabbage salted with CB was increased as the number of reuses increased (from 6.55 to 8.30 log CFU/g), whereas bacteria in cabbage salted with SF-EB was decreased (from 6.55 to 5.21 log CFU/g). These results show that SF-EB improved the reusability of brine by removing contaminated materials and by sterilization.

Keywords: salted cabbage, pre-filter system, electrolysis system, reuse brine, quality

INTRODUCTION

Chinese cabbage is the major ingredient in the preparation of kimchi. Salted Chinese cabbage, which is trimmed, washed, cut, and brined, is very popular with consumers because it facilitates kimchi preparation (1). However, the quality of salted Chinese cabbage can decrease during storage as its internal tissues are exposed to osmotic effects. Moreover, tissue metabolism is accelerated by physical damage. Therefore, a major concern regarding salted Chinese cabbage is to preserve its quality characteristics to extend the shelf life (2).

Large amounts of brine are used in the manufacturing of salted Chinese cabbage. Kimchi manufacturers reuse brine up to five times during the salting process to reduce salt consumption and to save the cost of waste water treatment. If brine is reused without adequate treatment, microorganisms and contaminants transferred from cabbage during the salting process can contaminate fresh cabbage when reused (2). To improve the hygiene of salted Chinese cabbage, studies have examined sterilization using ozone (O_3) (3), sterilization and washing using NaOCl (4), and pasteurization (5). However, problems have been found with these methods, including inadequate sterilization, long treatment times and negative influences on the texture of the salted Chinese cabbage. Other studies have examined the microbiological safety and reuse of brine, such as with filtering treatment (6), the use of electrodialysis (7), and sterilization using a microwave plasma sterilization system (2), but the methods are not applicable on an industrial scale due to insufficient effects or high operating costs. Consequently, developing a better sterilization process for the hygienic manufacture of salted Chinese cabbage and recycling of brine is needed.

An electrolysis system (ES) forms electrolyzed water by inducing the formation of NaOCl and HOCl using a NaCl solution and has sterilizing and washing effects. Using ES, we attempted to increase the reusability of brine by providing a sterilizing effect and, ultimately, to reduce harmful microorganisms while maintaining the quality of the manufactured salted Chinese cabbage. After repeating the salting process three to five times, the soil, dust, and mineral components such as magnesium and calcium, suspended solids and coloring components were transferred from the Chinese cabbage into the used brine during the salting process (8). Since these substances lower the performance of ES, they need to be removed using additional filtering equipment.

In this study, we assessed the effects of pre-filter sys-

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tems (PFS) and ES for the safe and efficient reuse of brine in the salting process. For this purpose, we first used PFS to remove various foreign materials that lower the performance of ES. Then, we investigated the optimal flow rate and current intensity of the PFS and ES, respectively. Finally, we evaluated the quality of the salted Chinese cabbage and the reused brine according to the number of times the brine was recycled by the PFS and ES during the salting process.

MATERIALS AND METHODS

Materials

Chinese cabbages harvested in Haenam, Korea and salt (80% NaCl, Yeonggwang, Korea) were purchased from a wholesale outlet in Cheongju, Korea and stored at 4°C until use. The nutrient agar used to analyze total bacteria was obtained from Difco Laboratories (Detroit, MI, USA).

Preparation of electrolyzed brine (EB)

EB was prepared using an ES (Lab Scale, TECHWIN, Cheongju, Korea) equipped with a MP-1000 volumetric pump (EYELA, Tokyo, Japan) to feed brine at 35 mL/min; the current was set at 0.2 A (9). As the salt content in the brine decreased after passing through the ES, the 13% salt content of the EB was maintained by adding more salt.

Effects of the PFS on the salting process of Chinese cabbage

The effects of PFS on removing various substances derived from the salting process of Chinese cabbage were evaluated by comparing the physicochemical and microbiological properties among the control brine (CB), EB, and the pre-filter (PF)-EB prepared by the PFS and ES during five cycles of the salting process. First, the CB, EB, and PF-EB were used in the next salting process after adjusting to 13% (w/v) salinity. Sediment and carbon filters (polypropylene, Triwell, Seoul, Korea) were used in the PFS. The sediment-filtered EB (SF-EB), carbon-filtered EB (CF-EB) and SF-CF-EB were prepared using PFS and ES at a 35 mL/min flow rate. Then, the salinity, pH, chlorine content, turbidity, and total bacterial count of each brine were analyzed.

Optimal ES conditions for the salting process of Chinese cabbage

To determine the optimal ES conditions for salting Chinese cabbage, we investigated the flow rate (mL/min) of brine and current (A) of the ES. First, the brine was passed through the SF-ES at 15, 25, and 35 mL/min flow rates and currents of 0.2, 1, and 2 A, and then SF-EBs prepared under various conditions were compared in terms of salinity, pH, chlorine content, turbidity, and total bacterial count.

Salting process of Chinese cabbage

After the inedible portion was removed, the Chinese cabbage was washed for 1 min with tap water through a nozzle (Φ 0.7 mm, 108 holes) at a speed of 18 L/min, and each head of cabbage was divided into four sections. The 13% (w/v) CB and 13% SF-EB were prepared according to the salting procedure for Chinese cabbage reported by Han and Noh (10) and then the prepared cabbage was salted for 15 h using 13% CB and 13% SF-EB, respectively. After the remaining salt on the surface of the cabbage was washed using the same process mentioned above and dried naturally for 30 min (11), the quality and microbiological properties of the salted Chinese cabbage were investigated.

Pretreatment of the Chinese cabbage and brine

Chinese cabbage samples (10 g) before and after the salting process were homogenized using a mixer (T50 Basic Ultra-Turax homogenizer, IKA® Werke GmbH & Co. KG, Staufen, Germany) with 50 mL distilled water for 5 min and then filtered through 8-μm Whatman filter paper (No. 2, Whatman, Inc., Shrewsbury, MA, USA). The brine samples were prepared from brine obtained before and after the salting process.

Salinity, pH, residual chlorine contents, and turbidity of cabbage and brine

The salinity and pH were measured using a salinity meter (ES-421, Atago Shrine, Tokyo, Japan) and pH meter (Orion 4 Star, Thermo Scientific, Waltham, MA, USA), respectively. The residual chlorine content was determined by an iodometric method using using a Chlorine Test kit (Spectroquant Nova-60, Merck, Darmstadt, Germany) (12). The detection range for this measurement was 0.03~6.00 mg/L. The brine was analyzed using a spectrophotometer (558 nm, UV1650PC, Shimadzu, Kyoto, Japan).

Texture and chromaticity analysis of Chinese cabbage

The textural properties of Chinese cabbage before and after the salting process were measured using a texture analyzer (TA-XT2, Stable Micro Systems, Surrey, UK) (13). The central portions of Chinese cabbage samples prepared with brine reused up to five times under the optimal ES conditions were analyzed. Samples measuring 3×3 cm were cut, pressed twice, and then measured consecutively using the texture analyzer for hardness and chewiness. Texture was analyzed using a 30% strain, 5.0-mm-diameter plunger, test speed of 1.0 mm/s, pretest speed of 1.0 mm/s, post-test speed of 1.0 mm/s, and contact force of 5.0 g. The chromaticity of the Chinese cabbage before and after salting was measured using a colorimeter (CR-300, Minolta, Osaka, Japan) for the Hunter L^* (lightness), a^* (redness), b^* (yellowness), and ΔE (color difference) values (14). All samples were measured 3 times using a white board as the reference color (L^*=93.5, a^*=0.31, and b^*=0.32).

Microbiological analysis

Chinese cabbage samples (10 g) before and after the salting process were transferred into a sterile stomacher bag (BPR-5590, WEGEN, Daejeon, Korea). Next, 90 mL 0.85% (w/v) sterile saline solution were added. The samples were homogenized using a stomacher (Stomacher 400, Seward Ltd., West Sussex, UK) for 1 min at normal speed and smeared on nutrient agar at a 10-fold dilution using sterile distilled water. The plates were incubated for 24 h at 37°C, the colonies counted as log CFU/g (salted cabbage) and log CFU/mL (brine), and the results compared.

Statistical analyses

Results are expressed as means±standard deviation (SD) and were subjected to analysis of variance using the SPSS 12.0 software (SPSS Inc., Chicago, IL, USA). Differences between sample means were determined as statistically significant at $P<0.05$ using Duncan's multiple comparison test (13). All experiments were performed in triplicate.

RESULTS AND DISCUSSION

Effects of PFS on reused brine in the salting process of Chinese cabbage

The comparison of physicochemical and microbiological properties of reused brines prepared using various PFS and ES during five cycles of the salting process is shown in Table 1. Changing the salinity of brines prepared using various PFS and ES showed that the salinity after the first salting process of Chinese cabbage was highest in the CB (9.9%), followed by the EB (9.7%), SF-EB (9.5%), CF-EB (6.1%), and SF-CF-EB (5.9%). However, the differences in salinity according to the number of brine reuse cycles did not change significantly ($P<0.05$). Additionally, when changes in the pH levels of the brines were compared, the pH was relatively higher in the CF-EB and SF-CF-EB than in the other treatment brines ($P<$

Table 1. Comparison of the physicochemical and microbiological properties of reused brine prepared using various pre-filter system and ES during 5 cycles of the salting process

No. of cycles	Properties	CB[1)]	EB	SF-EB	CF-EB	SF-CF-EB	F-value
1	Salinity (%)	9.93±0.06^{a}	9.67±0.06^{b}	9.50±0.10^{c}	6.14±0.01^{Bd}	5.87±0.03^{e}	3,274.4**
	pH	6.22±0.02^{Ab}	5.63±0.01^{Ac}	5.56±0.03^{Ad}	6.21±0.02^{Ab}	6.67±0.02^{Aa}	599.0**
	Residual chlorine (ppm)	0.29±0.03^{e}	20.72±0.55^{Ad}	22.07±0.10^{Ac}	63.00±0.50^{Ab}	64.87±0.40^{Aa}	12,847.2**
	Turbidity	0.042±0.001^{Ca}	0.038±0.002^{Cb}	0.031±0.001^{Cc}	0.016±0.002^{Cd}	0.005±0.001^{Ce}	209.9**
	Total bacterial count (log CFU/mL)	5.44±0.08^{C}	ND	ND	ND	ND	–
3	Salinity (%)	9.90±0.10^{a}	9.67±0.15^{b}	9.40±0.10^{c}	6.19±0.01^{Ad}	5.84±0.04^{e}	1,370.2**
	pH	5.18±0.02^{Bc}	5.21±0.03^{Bc}	5.05±0.03^{Bd}	6.15±0.02^{Ab}	6.56±0.02^{Ba}	1,372.5**
	Residual chlorine (ppm)	0.31±0.06^{e}	13.95±0.15^{Bd}	15.70±0.13^{Bc}	58.00±0.44^{Bb}	61.90±0.75^{Ba}	15,909.3**
	Turbidity	0.060±0.002^{Ba}	0.053±0.002^{Bb}	0.045±0.002^{Bc}	0.021±0.001^{Bd}	0.015±0.003^{Be}	199.6**
	Total bacterial count (log CFU/mL)	6.35±0.05^{B}	ND	ND	ND	ND	–
5	Salinity (%)	10.00±0.10^{a}	9.60±0.10^{b}	9.33±0.06^{c}	6.20±0.02^{Ad}	5.83±0.01^{e}	1,306.1**
	pH	4.86±0.02^{Cc}	4.87±0.02^{Cc}	4.71±0.03^{Cd}	6.03±0.02^{Bb}	6.52±0.01^{Ba}	2,973.4**
	Residual chlorine (ppm)	0.34±0.08^{e}	12.65±0.13^{Cd}	14.72±0.15^{Cc}	57.10±0.98^{Bb}	59.33±0.47^{Ca}	9,141.7**
	Turbidity	0.083±0.001^{Aa}	0.086±0.004^{Aa}	0.069±0.001^{Ab}	0.033±0.001^{Ac}	0.020±0.001^{Ad}	387.5**
	Total bacterial count (log CFU/mL)	8.49±0.09^{A}	0.67±0.58	ND	ND	ND	–
F-value	Salinity (%)	0.52	0.34	2.63	6.20*	1.31	
	pH	2,419.7**	531.2**	350.4**	22.30**	24.46**	
	Residual chlorine (ppm)	0.67	480.0**	2,007.9**	54.12**	70.41**	
	Turbidity	481.2**	129.2**	206.1**	108.10**	52.70**	
	Total bacterial count (log CFU/mL)	1,266.2**	–	–	–	–	

[1)]ES, electrolysis system; CB, control brine; EB, electrolyzed brine; SF, sediment filter; CF, carbon filter.
Values are mean±SD (n=3).
Different letters in the same properties (A-C) and row (a-e) are significantly different at $P<0.05$.
*$P<0.05$ and **$P<0.001$.
ND: not detected.

0.05). A comparison of the number of brine reuses revealed that the brine pH after five cycles of salting decreased sharply in the CB (pH 4.86), EB (pH 4.87), and SF-EB (pH 4.71) but decreased only slightly in the CF-EB (pH 6.03) and SF-CF-EB (pH 6.52). Based on these results, the salt in the brine was likely filtered out by the active carbon in the CF during the filtering process, and as a result, the salinity of the brine was lowered. Furthermore, a previous study showed that various soil, dust, minerals, and organic components are transferred from Chinese cabbage during the salting process, and alkalization is induced by the active carbon contained in the carbon filter (6,8).

The residual chlorine content in the brine samples was increased after passing through the PFS and ES, and the contents were highest in the SF-CF-EB, followed by the CF-EB, SF-EB, EB, and CB. As the number of brine reuses increased, the residual chlorine content in the CB was slightly increased from 0.29 to 0.34, whereas the residual chlorine content in the other brine samples was slightly decreased. The brine became more turbid as the number of brine reuses increased, but the SF-EB, CF-EB, and SF-CF-EB treated with the PFS tended to be less turbid compared with the CB and EB. The CB showed a slight increase in residual chlorine content, and salt was continuously added as the salting process was repeated. However, all other brine samples showed decreased residual chlorine content, because the residual chlorine consumed in the salting process was reproduced following ES treatment. Due to the repetition of the salting process, foreign materials transferred into the brine slowly accumulated and lowered electrolysis efficiency (6). Additionally, the increased turbidity in the CB and EB was likely due to the accumulation of various substances transferred from the Chinese cabbage during the repetition of the salting process. Conversely, the decreased turbidity in the SF-EB, CF-EB, and SF-CF-EB indicates that the foreign materials were removed by the PFS during these processes. Therefore, the use of the PFS in the present study likely removed these foreign materials and partially enhanced electrolysis efficiency due to the decreased turbidity and increased residual chlorine content.

Regarding microbiological properties, the total bacterial count was enhanced in the CB as the number of reuses increased, whereas bacteria in the EB and PF-EBs were not detected. This increase likely occurred because various microorganisms were transferred from the Chinese cabbage and accumulated in the brine during the repeated processes. Additionally, due to repeated use of the brine, the number of foreign materials accumulated, which in turn decreased the electrolysis efficiency and increased the amount of total bacteria detected in the brine after 5 reuses. In contrast, microorganisms were not detected in the EB or PF-EB samples due to the residual chlorine levels, the resulting sterilization effect generated by electrolysis of the salt water (15), and sterilization the wastewater induced by direct electrolysis of the brine (16). However, in the other brine samples treated with PFS, the electrolysis efficiency was maintained by removing foreign materials from the brines. As a result of this removal, the total bacterial levels were not detected in the brine samples after 5 reuses, because the brine was sterilized by the residual chlorine levels and by the ES. These results demonstrate the efficiency of the PFS for repeated use of brine. Additionally, although the turbidity remained very low, particularly in the CF-EB and SF-CF-EB, the low salinity and subsequent consumption of a large amount of salt made these brine samples economically inefficient. Furthermore, the high residual chlorine content (over 50 ppm) may have impaired the safety of the final (fifth) batch of salted Chinese cabbage.

The salinity in the EB and SF-EB was maintained at a specific level. The residual chlorine contents were higher than those in the CB, and a sterilization effect was observed; however, the electrolysis efficiency of the EB was reduced by various organic and inorganic compounds that accumulated in the brine following repeat use. In the SF-EB, microorganisms were not detected due to the removal of foreign materials by the FS, which caused the brine turbidity to remain low and the electrolysis efficiency to remain high. These findings indicate that the SF-EB process is the optimal PFS and ES for reusing brine in the manufacture of salted Chinese cabbage.

Optimal PFS and ES conditions for reusing brine

To determine the optimal PFS and ES conditions for reusing brine, ordinary brine was passed through an ES operating at 0.2, 1, or 2 A currents and 15, 25, and 35 mL/min flow rates, and the physicochemical and microbiological properties of the brine were compared (Table 2). A constant salinity was maintained regardless of the flow rate or current, but the pH levels decreased as the current intensity increased, likely because the quantity of H^+ ions generated from the anode increased due to the strong current as the brine passed through the electrolysis apparatus (12). In terms of residual chlorine and turbidity, when the flow rate was slow and the current intensity high, a large quantity of residual chlorine was produced, and the brine turbidity increased. The electrolysis efficiency of the salt in the electrolysis tank is likely enhanced by a slow flow rate and high current intensity in the brine, thereby increasing the amount of residual chlorine. In terms of the total bacterial count, no microorganisms were detected in any of the current conditions due to the sterilization effect. These findings suggest that the optimal PFS and ES conditions for the re-

Table 2. Comparison of the physicochemical and microbial properties of brines prepared under various electrolysis system conditions

Flow rate (mL/min)	Properties	Current (A)				F-value
		0	0.2	1	2	
15	Salinity (%)	9.87±0.06	9.77±0.12	9.73±0.06	9.77±0.06	1.7
	pH	6.23±0.02^{d}	6.70±0.01^{Ac}	6.97±0.01^{Ab}	7.37±0.03^{Aa}	2,341.8*
	Residual chlorine (ppm)	0.30±0.04^{d}	129.33±4.51^{Ac}	439.33±4.51^{Ab}	736.67±5.51^{Aa}	17,700.5*
	Turbidity	0.035±0.001^{d}	0.037±0.001^{Ac}	0.050±0.001^{Ab}	0.057±0.001^{Aa}	244.7*
	Total bacterial count (log CFU/mL)	5.26±0.03	ND	ND	ND	–
25	Salinity (%)	9.87±0.06	9.83±0.06	9.80±0.10	9.80±0.10	0.5
	pH	6.23±0.02^{d}	6.43±0.01^{Bc}	6.73±0.03^{Bb}	7.14±0.03^{Ba}	1,028.1*
	Residual chlorine (ppm)	0.31±0.03^{d}	84.00±5.00^{Bc}	304.67±8.33^{Bb}	595.67±5.03^{Ba}	9,254.5*
	Turbidity	0.035±0.001^{c}	0.035±0.001^{Ac}	0.044±0.001^{Bb}	0.051±0.001^{Ba}	112.4*
	Total bacterial count (log CFU/mL)	5.23±0.04	ND	ND	ND	–
35	Salinity (%)	9.87±0.06	9.83±0.06	9.77±0.12	9.77±0.06	1.1
	pH	6.23±0.01^{c}	6.19±0.03^{Cc}	6.45±0.02^{Cb}	6.70±0.02^{Ca}	291.1*
	Residual chlorine (ppm)	0.30±0.03^{d}	44.67±3.51^{Cc}	253.00±5.29^{Cb}	491.67±6.51^{Ca}	5,650.4*
	Turbidity	0.035±0.001^{c}	0.030±0.001^{Bd}	0.042±0.001^{Bb}	0.047±0.001^{Ca}	57.5*
	Total bacterial count (log CFU/mL)	5.30±0.03	ND	ND	ND	–
F-value	Salinity (%)		0.4	0.4	0.2	
	pH		418.5*	559.8*	566.1*	
	Residual chlorine (ppm)		154.5*	1,025.3*	1,125.4*	
	Turbidity		13.56*	25.6*	23.3*	
	Total bacterial count (log CFU/mL)		–	–	–	

Values are mean±standard deviation (n=3).
Different letters in the same properties (A-C) and in the same row (a-d) are significantly different at $P<0.05$.
*Significant at $P<0.001$.
ND: not detected.

use of brine include a 35 mL/min flow rate, resulting in the lowest residual chlorine content, and a 0.2 A current, at which microorganisms are not detected. The treatment efficiency for reuse is expected to be high if the brine is treated under optimal conditions.

Qualitative properties of Chinese cabbage salted with reused brine and prepared under the optimal PFS and ES conditions

Table 3 shows the qualitative properties of salted Chinese cabbage according to the number of reused brine cycles under the optimal PFS and ES conditions. When comparing CB and SF-EB according to the number of reuses, the salinity in the salted Chinese cabbage was higher than that in pre-salted Chinese cabbage. Although this salinity was maintained within a narrow range regardless of the number of reuses, there were no significant differences ($P>0.05$). This finding is similar to a previous study by Han and Noh (10), who showed that the salinity of Chinese cabbage increased from 0.2% before salting to 1.5～3.1% after salting due to the infiltration of salt in the brine into the Chinese cabbage via osmosis during the salting process (17).

In both the CB and SF-EB, the pH was 6.5 in the pre-salted Chinese cabbage but decreased to 6.2 in the salted Chinese cabbage as the number of brine reuses increased; the pH was maintained at this level. These findings are similar to the results obtained by Kim et al. (1) who found that the pH of Chinese cabbage decreased from 6.2～6.5 before salting to 5.9～6.0 after salting. This decrease likely occurred because of the transfer of organic acids from Chinese cabbage, as well as the production of organic acids during early fermentation by microorganisms (6). Furthermore, although the residual chlorine content of the salted Chinese cabbage increased slightly in both the CB and SF-EB, it was generally maintained at a low level. The standards for residual chlorine levels are required to be below 4 ppm in drinking water in Korea (18). Because the final residual chlorine content in the salted Chinese cabbage prepared by the SF-EB process in the present study was 0.29～0.39 ppm, it was considered safe for salting Chinese cabbage.

Comparison of the total bacterial count in salted Chinese cabbage revealed a continuous increase in the number of bacteria as the number of reuses increased. However, the total bacterial count decreased from 6.55 log CFU/g in pre-salted Chinese cabbage to 5.28 log CFU/g in salted Chinese cabbage prepared by the SF-EB process, suggesting the total bacterial count in the CB was increased due to the transfer and multiplication of microorganisms from the Chinese cabbage (6). In contrast, during the SF-EB salting process, the total bacterial count decreased, similar to a previous finding (3) that after sterilization of salted Chinese cabbage with 9 ppm

Table 3. Comparison of the physicochemical and microbial properties of Chinese cabbage salted with CB and SF-EB reused for 5 cycles of the salting process

	Properties			Before soaking	After 1st soaking	After 3rd soaking	After 5th soaking	F-value
CB	Salinity (%)			0.30 ± 0.10^{b}	1.90 ± 0.30^{a}	1.80 ± 0.40^{a}	2.10 ± 0.40^{a}	22.83^{**}
	pH			6.53 ± 0.02^{a}	6.23 ± 0.07^{b}	6.22 ± 0.07^{b}	6.28 ± 0.05^{b}	19.74^{**}
	Residual chlorine (ppm)			0.20 ± 0.02^{b}	0.24 ± 0.02^{b}	0.31 ± 0.03^{a}	0.30 ± 0.03^{a}	11.80^{**}
	Total bacterial count (log CFU/g)			6.55 ± 0.07^{d}	6.78 ± 0.05^{c}	7.27 ± 0.07^{b}	8.30 ± 0.09^{a}	368.03^{**}
	Texture	Hardness (g)		827.3 ± 5.4^{c}	$1,477.9\pm69.5^{a}$	$1,483.9\pm69.5^{a}$	958.7 ± 44.3^{b}	121.81^{**}
		Chewiness (g)		745.4 ± 12.6^{a}	345.5 ± 47.2^{b}	404.8 ± 19.6^{b}	262.0 ± 37.5^{c}	129.52^{**}
	Color	Leaf	*L*	79.89 ± 2.07^{a}	76.54 ± 1.91^{b}	76.03 ± 1.68^{b}	74.50 ± 0.83^{b}	5.41^{**}
			a	−6.44±0.15	−6.37±0.10	−6.38±0.12	−6.50±0.21	0.47
			b	28.11±1.36	27.67±1.02	27.73±0.36	28.06±1.08	0.15
			ΔE	–	3.42	4.12	6.37	–
		Stem	*L*	78.61 ± 1.63^{a}	75.11 ± 0.47^{b}	74.15 ± 0.87^{b}	73.46 ± 0.94^{b}	13.76^{**}
			a	−0.92±0.07	−0.91±0.03	−0.93±0.06	−0.93±0.09	0.07
			b	3.73±0.09	3.66±0.07	3.78±0.14	3.83±0.18	1.01
			ΔE	–	3.50	5.22	7.11	–
SF-EB	Salinity (%)			0.30 ± 0.10^{b}	2.00 ± 0.20^{a}	2.10 ± 0.20^{a}	2.00 ± 0.20^{a}	68.63^{**}
	pH			6.53 ± 0.02^{a}	6.20 ± 0.02^{b}	6.20 ± 0.03^{b}	6.21 ± 0.03^{b}	131.81^{**}
	Residual chlorine (ppm)			0.20 ± 0.02^{b}	0.29 ± 0.07^{ab}	0.39 ± 0.09^{a}	0.39 ± 0.07^{a}	5.37^{*}
	Total bacterial count (log CFU/g)			6.55 ± 0.07^{a}	5.28 ± 0.10^{b}	5.25 ± 0.10^{b}	5.21 ± 0.04^{b}	197.32^{**}
	Texture	Hardness (g)		827.3 ± 5.4^{b}	$1,441.1\pm48.1^{a}$	$1,422.4\pm42.7^{a}$	$1,450.2\pm62.2^{a}$	139.56^{**}
		Chewiness (g)		745.4 ± 12.6^{a}	375.9 ± 33.6^{b}	395.2 ± 15.6^{b}	378.9 ± 22.1^{b}	195.31^{**}
	Color	Leaf	*L*	79.89 ± 2.07^{a}	75.87 ± 0.50^{b}	74.88 ± 0.46^{b}	75.93 ± 0.21^{b}	12.30^{**}
			a	−6.44±0.15	−6.45±0.09	−6.58±0.09	−6.50±0.19	0.64
			b	28.11±1.36	27.78±0.95	27.98±1.10	28.36±0.70	0.16
			ΔE	–	4.04	5.29	4.93	–
		Stem	*L*	78.61±1.63	75.35±0.87	75.60±0.69	77.65±5.78	0.81
			a	−0.92±0.07	−0.92±0.06	−0.91±0.03	−0.91±0.08	0.03
			b	3.73±0.09	3.67±0.12	3.75±0.06	3.81±0.13	1.05
			ΔE	–	3.25	3.78	2.90	–

CB, control brine; SF-EB, sediment-filtered electrolyzed brine.
Values are mean±standard deviation (n=3).
Different letters (a-d) in the same row are significantly different at $P<0.05$.
$^{*}P<0.05$ and $^{**}P<0.001$.

ozone using ozone disinfection technology, the bacterial count was 0.9 log CFU/g lower than ordinary salted Chinese cabbage (6.8 log CFU/g). These results were probably due to the possibility that cross-contamination is low during the sterilization of SF-EB itself, and the bacteria in Chinese cabbage are deactivated by SF-EB. In this study, Chinese cabbage salted using the CB process had a bacterial count of 7.27 log CFU/g after three uses and 8.30 log CFU/g after 5 uses. Therefore, the general brine should not be reused more than 3 times. However, the Chinese cabbage salted using the SF-SB process had a general bacterial count as low as 5.21 log CFU/g after five uses, so this brine could possibly be reused five or more times.

The chromaticity of the leaves and stems of salted Chinese cabbage was assessed according to the number of brine reuses under the optimal PFS and ES conditions. The L^* values (lightness) decreased significantly in both the CB and SF-EB as the number of reuses increased, but the a^* and b^* values remained constant. When the ΔE values were compared, they increased in the CB to 6.37 (leaf) and 7.11 (stem) as the number of reuses increased and to 5.29 (leaf) and 3.78 (stem) in the SF-EB. When the color difference was determined according to the regulations of the U.S. National Bureau of Standards (Trace, 0.0～0.5; Slight, 0.5～1.5; Noticeable, 1.5～3.0; Appreciable, 3.0～6.0; Much, 6.0～12.0; Very Much, > 12.0) (19), the color difference after repeated salting during the SF-EB process was Appreciable for both the leaves and stems, but when the cabbage was salted repeatedly during the CB process, the color difference was Much. These findings indicate that the color of the salted Chinese cabbage exhibited a greater degree of change when salted using CB compared with SF-EB.

Regarding texture changes in the salted Chinese cabbage according to the number of reuses under optimal PFS and ES conditions, the hardness increased following both the CB and SF-EB processes, but chewiness decreased as the number of brine uses increased. Increased hardness of salted Chinese cabbage compared with fresh Chinese cabbage was expected, because the air inside the plant tissue is degassed and water is eluted, and as a result, the cell walls stack up (20). The water inside the plant tissue drains out into the brine through the cell membrane, and then the Na^+ in the brine infiltrates into the cells. Subsequently, a partial substitution reaction occurs between Na^+ and Ca^{2+} or Mg^{2+}, which are cross-linked to pectin, and then the Na^+ disrupts the hydrogen bond between pectin and cellulose. As this substitution reaction progresses, the bearing capacity is further weakened, and the chewiness of the plant decreases (21).

Furthermore, if pressure is applied to fresh Chinese cabbage, it is transmitted to the plant and creates turgor pressure, which presses and deforms the vacuoles. Subsequently, resilience occurs, which is partially due to the pressure applied to cell walls, and the combination of these factors working close together creates rigidity and crispness evident in the texture of the product (22). In the CB, the microorganisms multiplied considerably as the brine was used repeatedly. Because microorganisms decompose live plant material and affect texture (1), the microorganisms may have multiplied after CB was used five times, and this process affected the texture of the Chinese cabbage during the salting process. Compared with the CB process, SF-EB may preserve the texture of the salted Chinese cabbage and, consequently, contribute to the maintenance of the kimchi texture during its manufacturing.

Qualitative properties of reused brine according to the number of reuses under optimal PFS and ES conditions

The qualitative and microbiological properties of CB and SF-EB after five cycles of reuse during the salting process are shown in Table 4. Salinity according to the number of brine reuses under optimal PFS and ES conditions decreased in both the CB and SF-EB, although it was slightly higher in the CB than SF-EB ($P<0.05$). In both the CB and SF-EB, salt was added for the subsequent salting process to 13% (w/v) salinity, which was maintained within a constant range throughout the salting process despite repeated brine use. Salinity likely decreased during the salting process of the Chinese cabbage due to infiltration of the salt in the brine into Chinese cabbage via osmosis (4). Moreover, as the brine was treated by the PFS and ES, the salt in the brine was electrolyzed and consumed as electrolyzed water, which reduced the salinity in the SF-EB compared with the CB (23).

The pH of the CB and SF-EB decreased during the Chinese cabbage salting process and was slightly lower in the SF-EB than CB. Additionally, in both the CB and SF-EB, the turbidity was greater after than before the salting process, although lower in the SF-EB ($P<0.05$). The residual chlorine content in the CB was maintained at very low levels before and after salting, but the residual chlorine content in the SF-EB decreased sharply after salting. Huang et al. (24) showed that the residual chlorine content in electrolyzed water produced by ES exhibits a sterilization effect and volatilizes quickly. Thus, the decrease in residual chlorine content was likely due to the characteristics of the electrolyzed water and to accumulation of the components transferred out of the Chinese cabbage as the number of brine reuses increased and the electrolysis efficiency decreased (8).

The total bacterial count increased rapidly in the CB after the salting process and increased continuously as the number of brine reuses increased, but no bacteria were detected in the SF-EB. Jung et al. (4) found that the total bacterial count in CB was 5.2 log CFU/mL after one use, increasing sharply to 8.7 log CFU/mL after 5 uses. In the SF-EB, the foreign materials were removed from the Chinese cabbage by the SF and prepared using ES, and the microorganisms were possibly deactivated by the direct and indirect sterilization effects of ES. These

Table 4. Comparison of the physicochemical and microbiological properties of Chinese cabbage salted with CB and SF-EB reused for 5 cycles of the salting process

	Properties	Before soaking	After 1st soaking	After 3rd soaking	After 5th soaking	F-value
CB	Salinity (%)	13.1±0.1^a	10.2±0.5^b	10.3±0.7^b	10.2±0.4^b	31.64*
	pH	8.35±0.10^a	6.14±0.11^b	5.26±0.05^c	5.08±0.08^d	944.9*
	Residual chlorine (ppm)	0.28±0.02	0.31±0.02	0.33±0.03	0.31±0.03	2.20
	Turbidity	0.019±0.003^d	0.041±0.003^c	0.076±0.002^b	0.112±0.005^a	458.4*
	Total bacterial count (log CFU/mL)	1.17±0.16^d	5.32±0.05^c	6.72±0.12^b	8.35±0.11^a	2,053.9*
SF-EB	Salinity (%)	13.0±0.1^a	9.5±0.1^b	9.5±0.2^b	9.4±0.2^b	381.29*
	pH	6.08±0.10^a	5.39±0.08^b	5.01±0.04^c	4.63±0.12^d	139.2*
	Residual chlorine (ppm)	40.95±0.03^a	20.54±1.30^b	16.51±0.82^c	15.86±0.96^c	287.1*
	Turbidity	0.029±0.003^c	0.032±0.004^c	0.043±0.005^b	0.062±0.006^a	83.58*
	Total bacterial count (log CFU/mL)	ND	ND	ND	ND	—

CB, control brine; SF-EB, sediment-filtered electrolyzed brine.
Values are mean±standard deviation (n=3).
Different letters (a-d) in the same row are significantly different at $P<0.05$.
*Significant at $P<0.001$.

results show that SF-EB improves brine reusability by removing contaminated materials and by its sterilizing effects.

In conclusions, when the brine was reused during the salting process for the manufacturing of kimchi, the quality of the salted Chinese cabbage deteriorated due to the accumulation of various foreign materials transferred from the Chinese cabbage and from the multiplication of microorganisms. However, if PFS and ES can be applied, the brine could possibly be reused while maintaining the quality of the salted Chinese cabbage, by removal of foreign materials through the pre-filter and by the sterilizing effects of ES. These findings will contribute to the economic efficiency of the kimchi and salted Chinese cabbage industries and manufacturing of safe kimchi.

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AUTHOR DISCLOSURE STATEMENT

The authors declare no conflict of interest.

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