ISSN(Print) : 1738-7248, ISSN(Online) : 2287-7428
Korean J. Food Preserv.
23(7), 913-922 (2016)
http://dx.doi.org/10.11002/kjfp.2016.23.7.913

사단법인 한국식품저장유통학회
The Korean Society of Food Preservation

Optimization of supplementation with maltodextrin and grape seed extract for improving quality of shredded Korean cabbage (*Brassica rapa* L. ssp. Pekinensis) during salting process

Sang-Un Park, Eun Ji Choi, Young Bae Chung, Eung Soo Han, Hae Woong Park, Ho Hyun Chun*
Advanced Process Technology and Fermentation Research Group, World Institute of Kimchi, Gwangju 61755, Korea

절임 공정 중 절단 배추의 품질 향상을 위한 maltodextrin과 grape seed extract 첨가조건 최적화

박상언 · 최은지 · 정영배 · 한응수 · 박해웅 · 천호현*
세계김치연구소 신공정발효연구단

Abstract

The aim of this study was to develop a new salting condition that included added maltodextrin (MD) and grape seed extract (GSE) to ensure the microbiological safety and quality of salted shredded Korean cabbage. Response surface methodology (RSM) was used to analyze the effects of four independent variables (NaCl concentration, salting duration, MD concentration, and GSE concentration). The following response variables were evaluated: reduction in total aerobic bacteria, yeast, and mold counts; weight loss and salt content; and taste, texture, and overall acceptability of salted shredded Korean cabbage. The optimal salting conditions include a combination of 10.09~10.32% NaCl, 9.45~10.00% MD, and 234~300 ppm GSE in a ternary salting solution and a salting duration of 5.68~5.94 hr. This optimal combination reduced total aerobic bacterial and yeast/molds counts by 3.33 and 1.45 log CFU/g, respectively, while maintaining high sensory scores for taste, texture, and overall acceptability of the salted shredded Korean cabbage. In addition, the optimal conditions yielded more acceptable weight loss and salt content characteristics. The results suggest that use of the optimized combination of salting conditions can improve the microbiological safety and quality of salted shredded Korean cabbage used for commercial kimchi production.

Key words : Korean cabbage, grape seed extract, maltodextrin, response surface methodology, salting

Introduction

Kimchi is a globally popular side dish because of its taste and functional characteristics (1). In Korea, kimchi is traditionally prepared and consumed at home. However, given the increasing number of people who consume meals at work or in schools or restaurants, kimchi is now produced by large-scale commercial manufacturers (2). Kimchi is produced by mixing and fermenting shredded or bisected, salted *Brassica rapa* L. ssp. Pekinensis (Korean cabbage) with other ingredients. These other ingredients include radish, garlic, ginger, rice paste, and dried red pepper powder. Salted Korean cabbage is processed by trimming, salting, washing, and draining (3); the salting process is a particularly critical determinant of quality of final product.

A major challenge in the preparation of salted Korean cabbage is that it cannot be heated during processing to eliminate pre-existing microorganisms (4,5). Although the

*Corresponding author. E-mail : hhchun@wikim.re.kr
Phone : 82-62-610-1761, Fax : 82-62-610-1850
Received 10 August 2016; Revised 14 November 2016; Accepted 23 November 2016.

cabbage is normally cleaned in chilled water or chemical sanitizer prior to blending with kimchi seasoning, microbial contamination is inevitable (5); even industrial processing of kimchi does not guarantee the elimination of foodborne pathogens (3). In Korea in 2012, 1,642 people were infected by pathogenic *Escherichia coli* after consuming kimchi (6). Outbreaks of food poisoning caused by kimchi contaminated with norovirus were reported at three schools (7).

A good manufacturing practice for decreasing the microbial load in salted Korean cabbage and improving safety after the salting step is the use of surface decontamination techniques to eliminate external pathogens. To this end, various washing treatments, including with electrolyzed water (8), chlorine (9), ozone (10), and organic acid (5), have been used. However, these processes can change the textural and nutritional properties of cabbage (5); moreover, residual chemical elements of sanitizers (e.g., chlorine) on the food surface can cause health problems (11,12). Therefore, a sanitation method that is effective, non-toxic, and easily applicable during the salting process is desired.

Grape seed extract (GSE) has many advantages over existing sterilization methods (13) because it does not require chemicals or heat. The extract from grape seeds is dried and purified, yielding polyphenolic compounds that have antioxidant, antimicrobial, and anti-inflammatory properties (14,15). Moreover, GSE as a food-grade preservative for control of surface microorganisms has received a Generally Recognized as Safe designation by the Food and Drug Administration (16). Inactivation studies have demonstrated the effectiveness of GSE in reducing the amount of pathogenic bacteria and spores in vegetables and fruits (17).

The appropriate salt content and weight loss (water loss and solid gain) for salted Korean cabbage used to prepare kimchi are approximately 1.5~2.0% and 15~25%, respectively (18). Some manufacturers have used tepid water (30~40℃) to reduce the time required to achieve target salt characteristics (5). However, warm temperatures can provide a favorable environment for the proliferation of mesophilic bacteria, including spoilage, fecal, or pathogenic bacterial species (3,4). In contrast, salting at cold temperature prolongs the time required to achieve optimal salt content and weight loss, and is impractical in a commercial processing plant (3). There is therefore a need in the kimchi manufacturing industry to establish efficient salting conditions that inhibit bacterial growth while reducing processing time at low temperatures.

Maltodextrin (MD) is a food additive used to increase the specific gravity of food products. Molecular-press dehydration using MD, which is mainly based on cytorrhysis, has been extensively studied (19,20); this process is similar to osmotic dehydration, except that the size of the dehydrating agent differs (19). Plant cells can be dehydrated because they contract as a result of the osmotic pressure applied by MD molecules to the cell wall in solution; however, the polymers cannot pass through the cell wall owing to their large size (21). Therefore, MD may be an effective dehydrating agent for the salting of Korean cabbage.

Response surface methodology (RSM) is a statistical method based on the multivariate nonlinear model that has been widely used in the food processing industry (22). Because it is less labor-intensive than other approaches, RSM is one of the most popular optimization techniques currently in use (23). Some studies have attempted to reduce microbial counts in salted Korean cabbage using classical single-factor optimization techniques (12), which is time-consuming and provides little information on interactions among the various factors that can influence the sensory qualities of the product and make it palatable to consumers (24).

The objective of this study was to establish the optimum combination of NaCl, MD, and GSE in the salting solution and the ideal salting time. Such optimization would enable inactivation of pre-existing microorganisms and improvement of salted-shredded Korean cabbage quality using RSM.

Materials and Methods

Sample preparation

Korean cabbage (*B. rapa* L. ssp. Pekinensis cv. Hwiparam) was cultivated in the field and harvested in early November, 2015 in Haenam-gun, Korea. The outer leaves and foreign substances were removed, and the remaining leaves were evenly shredded into pieces of approximately 4×4 cm using a knife sterilized before use by dipping into 70% alcohol and flaming.

Experimental design

RSM was used to analyze the effects of four independent variables (NaCl concentration, salting time, MD concentration, and GSE concentration) on the following response variables: reduction in total aerobic bacteria, yeast, and mold counts; weight loss and salt content; and taste, texture, and overall acceptability of the salted shredded Korean cabbage. The range and levels of each variable are summarized in Table 1. The ranges of the experimental parameters were selected based on preliminary experiments.

Table 1. Levels of variables for an experimental design

Independent variables	Levels		
	-1	0	1
NaCl (%)	5	10	15
Salting time (hr)	2	5	8
Maltodextrin (%)	0	5	10
Grape seed extract (ppm)	0	150	300

The experiments were performed according to a previously described central composite design (25), with some modifications. In this study, the experimental combinations were at the midpoints of edges and at the center of the process space. In total, 20 combinations of four independent variables were used (Table 2). Each experiment was performed in triplicate.

Preparation of salting solution supplemented with MD or GSE and salting process

Brine as a salting solution (5~15% NaCl, w/v) was prepared by dissolving commercially refined salt (purity: >99.5%; Hanju Co., Ulsan, Korea) in tap water. MD (dextrose equivalent: 15~20; Daesang Co., Gunsan, Korea) solution at concentrations of 5 and 10% was prepared by diluting with 5, 10, and 15% brine. The salting solution was agitated for 30 min, and GSE (DF-100; Food Additive Bank Co., Anseong, Korea) was dissolved in the solution with or without MD to final concentrations of 150 and 300 ppm. All solutions were freshly prepared on the day of the experiment. Shredded Korean cabbage samples were treated by immersion into the 20 solutions comprising different combinations of 5~15% NaCl, 0~10% MD, and 0~300 ppm GSE at a ratio of 1:5 (w/v) for a salting time of 2~8 hr. After salting, each cabbage sample was washed twice with distilled water for subsequent experiments.

Table 2. Central composite experiment design for the combination of NaCl, MD[1)], and GSE[2)] concentrations in the salting solution and salting time

Run	Independent variables[3)]				Response variables						
	X_1	X_2	X_3	X_4	Total aerobic bacteria (log CFU/g)	Yeast/molds (log CFU/g)	Taste	Texture	Overall acceptability	Weight loss (%)	Salinity (%)
1	-1 (5)	1 (8)	1 (10)	1 (300)	3.18	2.72	6.51	6.32	7.10	11.77	0.89
2	1 (15)	1 (8)	1 (10)	-1 (0)	4.30	2.95	5.10	4.94	4.88	20.95	3.48
3	0 (10)	0 (5)	0 (5)	0 (150)	3.31	2.51	7.11	6.25	7.20	12.12	1.81
4	-1 (5)	-1 (2)	-1 (0)	1 (300)	3.28	2.54	4.63	5.13	4.75	5.35	0.77
5	1 (15)	-1 (2)	-1 (0)	-1 (0)	3.70	3.18	6.25	5.38	6.38	9.30	2.49
6	-1 (5)	-1 (2)	1 (10)	-1 (0)	4.75	3.32	4.52	5.22	3.75	5.73	0.69
7	-1 (5)	1 (8)	-1 (0)	-1 (0)	4.92	3.21	6.13	5.88	6.38	10.82	1.13
8	0 (10)	0 (5)	0 (5)	0 (150)	3.48	2.81	7.11	5.98	7.30	11.82	1.8
9	1 (15)	-1 (2)	1 (10)	1 (300)	3.22	2.63	4.75	5.25	4.97	13.23	2.33
10	1 (15)	1 (8)	-1 (0)	1 (300)	3.48	2.82	4.61	4.88	3.92	18.03	4.16
11	1 (15)	1 (8)	-1 (0)	-1 (0)	4.14	3.45	4.40	5.14	4.15	14.81	4.25
12	-1 (5)	-1 (2)	1 (10)	1 (300)	3.75	2.79	4.75	5.22	4.88	6.00	0.69
13	1 (15)	-1 (2)	-1 (0)	1 (300)	2.82	2.64	6.24	5.38	6.08	8.11	2.77
14	-1 (5)	-1 (2)	-1 (0)	-1 (0)	4.88	3.26	4.51	5.04	4.88	4.88	0.89
15	1 (15)	-1 (2)	1 (10)	-1 (0)	3.53	3.36	5.43	5.38	5.52	12.44	2.18
16	-1 (5)	1 (8)	1 (10)	-1 (0)	4.74	3.53	7.50	6.63	7.38	12.92	0.98
17	1 (15)	1 (8)	1 (10)	1 (300)	3.14	2.65	4.88	4.88	4.63	23.43	3.67
18	-1 (5)	1 (8)	-1 (0)	1 (300)	3.22	2.44	6.56	6.38	6.70	12.04	1.24
19	0 (10)	0 (5)	0 (5)	0 (150)	3.55	2.65	7.12	6.11	7.42	13.42	1.93
20	0 (10)	0 (5)	0 (5)	0 (150)	3.27	2.54	7.33	6.20	7.50	12.66	1.89

1)MD, maltodextrin.
2)GSE, grape seed extract.
3)Independent variables: X_1 (NaCl concentration, %), X_2 (Salting time, hr), X_3 (MD concentration, %), X_4 (GSE concentration, ppm).

Microbiological analysis

For microbiological analysis, samples (25 g) were first mixed with 225 mL peptone water (0.1% sterile peptone, w/v) in a sterile Stomacher bag with a polyethylene filter layer. They were then homogenized using a Stomacher MIX 2 instrument (AES Laboratoire, Combourg, France) for 3 min, and diluted with peptone water for microbial counts. Serial dilutions were prepared in triplicate. For total aerobic bacterial counts, samples were spread on 3M Petrifilm Aerobic Count Plates (3M Co., St. Paul, MN, USA) and incubated at 37℃ for 48 hr, whereas yeast/molds were spread on 3M Petrifilm Yeast and Molds Count Plates (3M Co.) and incubated at 25℃ for 72 hr. Three replicates were prepared for each plate, and counts are expressed as log CFU/g.

Sensory evaluation

Salted shredded Korean cabbage was analyzed for taste, texture, and overall acceptability by 30 trained panelists (15 men and 15 women; age range, 25~45 years) at room temperature (22℃±1℃). Samples (100 g) were presented on a plastic dish under normal light conditions. The sensory qualities of the samples were evaluated according to a 9-point scale as follows: 8 or 9, very good; 6 or 7, good; 4 or 5, fair; 2 or 3, poor; and 1, very poor. All experiments were performed in triplicate with three observations per trial.

Weight loss

Weight loss results from water loss and solid gain during osmotic dehydration. After the salting process, the weight loss of shredded Korean cabbage was calculated as follows:

Weight loss (%)=[fresh Korean cabbage weight (g)-salted and dehydrated Korean cabbage weight (g)]/fresh Korean cabbage weight (g)×100.

Salt content

The salt content of each sample was measured using Mohr's titration method (4). Samples (1 g) were homogenized in 99 mL distilled water and then passed through Whatman No. 2 filter paper (Whatman, Springfield, UK). A 1-mL volume of 2% potassium chromate indicator was added to 10 mL of the filtered sample solution, and this mixture was titrated against 0.02 N $AgNO_3$ (Daejung Chemicals & Metals Co., Siheung, Korea) until a red-brown color (i.e., the end point) was observed.

Statistical analysis

Statistical analysis was performed using Design-Expert v.10 software (Stat-Ease, Minneapolis, MN, USA); results represent the average of four independent measurements. The response was expressed as a function of the independent variables defined by the following quadratic polynomial model:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{34}X_3X_4 + b_{11}X_{12} + b_{22}X_{22} + b_{33}X_{32} + b_{44}X_{42}$$

where Y is a dependent variable and b_0 is a constant. The coefficients (b_1, b_2, b_3, and b_4), (b_{12}, b_{13}, b_{14}, b_{23}, b_{24}, and b_{34}), and (b_{11}, b_{22}, b_{33}, and b_{44}) represent the linear, interaction, and quadratic coefficients, respectively, of the model, and X_1, X_2, X_3, and X_4 represent the independent variables. The goodness of fit of the model was evaluated based on the coefficient of determination (R^2) and adjusted R^2 (R^2_{adj}). The significance of all terms in the polynomial equation was assessed by computing F values and was analyzed at probability levels of $p<0.05$, 0.01, or 0.001.

Optimization

Numerical optimization was performed to improve the microbiological safety and quality of salted shredded Korean cabbage through analysis of superimposed contour plots of the response variables using Design-Expert v.10 software.

Results and Discussion

Microbiological safety of salted shredded Korean cabbage

The initial counts of total aerobic bacteria and yeast/molds on salted shredded Korean cabbage were 6.38 and 3.87 log CFU/g, respectively. These results are similar to those from a previous study that found high levels of total aerobic bacteria (5.2~7.6 log CFU/g) and yeast/molds (2.5~4.3 log CFU/g) in Korean cabbage (5,10). Such cabbage can be contaminated by various microorganisms, including pathogenic bacteria, during the salting process (9). High microbial counts on salted Korean cabbage can reduce the shelf life of kimchi products and increase consumer concerns regarding kimchi-related illness. Therefore, sterilizing salted Korean cabbages is necessary to ensure long shelf life and consumer safety.

We evaluated the goodness of fit of the quadratic model applied to microbial reduction in Korean cabbage salted under different conditions by calculating R^2 (Table 3). In general, R^2 or R^2_{adj} values close to 1 indicate goodness of fit of the quadratic model to the experimental results (25,26).

Table 3. Coefficients of second-order polynomial equations and significance of each model and dependent response variables for salted shredded Korean cabbage treated with various combinations of NaCl, MD[1], and GSE[2] concentrations in the salting solution and salting time

	Microbiological analysis		Sensory evaluation			Salting characteristics	
	Total aerobic bacteria	Yeast/molds	Taste	Texture	Overall acceptability	Weight loss	Salt content
R^2	0.955	0.809	0.960	0.975	0.984	0.981	0.992
R^2_{adj}	0.903	0.770	0.934	0.955	0.970	0.958	0.989
Intercept b_0	3.44	2.70	7.14	6.07	7.35	11.99	2.00
Linear b_1	-0.25***[3]	-6.606E-003	-0.26**	-0.30***	-0.34***	3.17***	1.13***
b_2	0.10*	-	0.32**	0.18***	0.25**	3.73***	0.44***
b_3	0.10*	-	-8.125E-003	0.04	-1.250E-003	1.45***	-0.17***
b_4	-0.49***	-0.27***	-	-3.750E-003	-0.02	-	-
Interaction b_{12}	-[4]	-	-0.71***	-0.39***	-0.91***	-	0.29***
b_{13}	-	-	-0.19*	-0.08*	-	1.03*	-0.08*
b_{14}	0.11*	-	-	-	-0.15*	-	-
b_{23}	-	-	0.29**	-	0.36***	-	-
b_{24}	-0.08	-	-	-	-	-	-
b_{34}	-	-	-	-0.06	-	-	-
Quadratic b_{11}	0.23*	0.22*	-1.77***	-0.65***	-1.96***	-	-
b_{22}	-	-	-	-	-	-	-
b_{33}	-	-	-	-	-	-	-
b_{44}	-	-	-	-	-	-	-

[1]MD, maltodextrin.
[2]GSE, grape seed extract.
[2]*, $p<0.05$; **, $p<0.01$; ***, $p<0.001$.
[4]Non-significant factors were removed.

The high R^2 value obtained here indicates that all of the predicted values had a good fit (26).

The analysis of variance (ANOVA) showed that the quadratic polynomial model adequately represented the experimental data, with R^2 values of 0.955 and 0.809 for the reductions in total aerobic bacteria and yeast/mold counts, respectively. R^2_{adj} corrects R^2 according to sample size and number of terms in the model; in cases where there are many terms in the model and the sample size is small, R^2_{adj} is less than R^2, indicating that the model is inadequate (26). The R^2_{adj} of total aerobic bacteria and yeast/molds was 0.903 and 0.770, respectively, for the model; this was similar to the R^2 values, indicating good agreement between the experimental and predicted reductions in total aerobic bacteria and yeast/molds in shredded Korean cabbage during the salting process.

The p value was used to assess the significance of each term representing the interactions among variables (25); smaller p values indicate greater significance of the corresponding coefficient (25-27). The regression coefficients in Table 3 show that the linear terms of the GSE concentration had significant effects on microbial inactivation in salted shredded Korean cabbage ($p<0.001$).

NaCl and GSE concentrations had significant positive effects on reducing the counts of total aerobic bacteria ($p<0.05$). The quadratic term of the NaCl concentration indicated a significant positive effect on the reduction of total aerobic bacteria and yeast/mold counts ($p<0.05$). However, the quadratic terms of salting time, MD concentration, and GSE concentration did not significantly influence reductions in total aerobic bacteria or yeast/mold counts.

Response surface plots were generated to better visualize the combined effects of the four independent variables on the reduction in the amount of total aerobic bacteria (Fig. 1a) and yeast/molds (Fig. 1b) on shredded Korean cabbage treated with different NaCl and GSE concentrations at a fixed salting time of 5 hr and MD concentration of 5%. The magnitude of the reduction in total aerobic bacteria count increased as the GSE and NaCl concentrations increased, whereas the change in the reduction in yeast/mold count was less obvious, implying that the effect of GSE and NaCl on reducing the counts of preexisting microorganisms depends on the type of microbe present. It was previously shown that GSE treatment suppressed growth in gram-negative and -positive bacteria but was less effective against yeast and molds (14). Yeast showed greater resistance to NaCl (water activity) than bacteria (27). Additionally, the minimum inhibitory concentration of GSE was previously reported to be 850~1,000 and 1,250~1,500 ppm for gram-positive and -negative bacteria, respectively (28). However, we found that a GSE concentration of 300 ppm effectively inactivated native microbial flora in salted shredded Korean cabbages. This discrepancy can be explained by differences in treatment time, salt concentration, and surface topography in our study as compared to the previous reports. The use of chemical sanitizers is linked to the generation of carcinogenic compounds (29); as such, alternative methods to reduce microorganism contamination of processed salted Korean cabbage by non-thermal means are desired. GSE is favored as a preservative for various foods owing to its low toxicity (LD50=2,900 mg/kg) to humans (30). Indeed, in the present study GSE supplementation of brine reduced the total aerobic bacteria and yeast/mold counts on shredded Korean cabbage during salting.

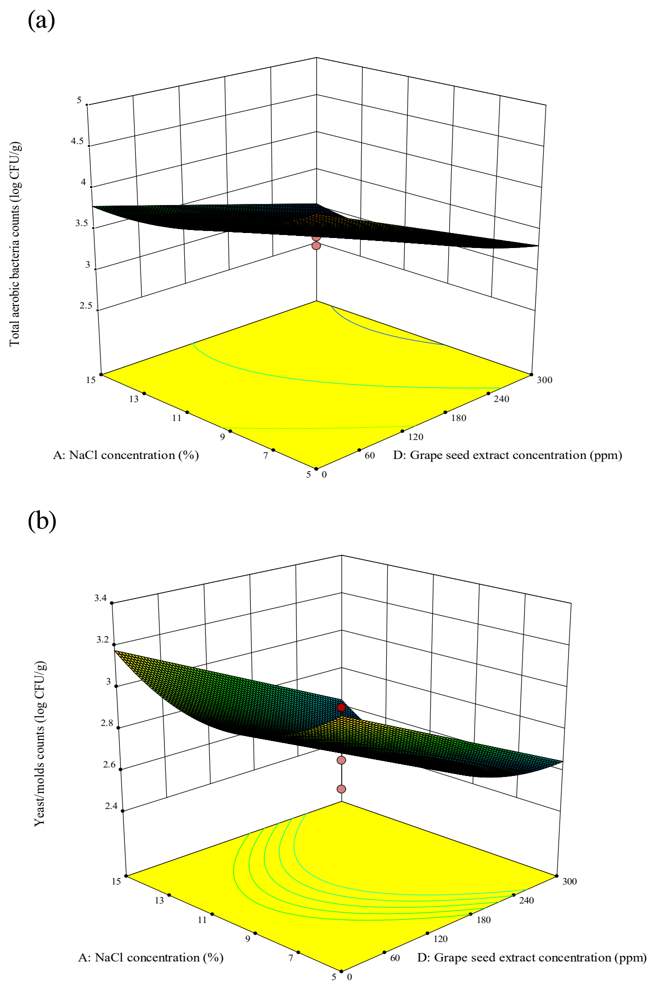

Fig. 1. Response surface plots for reduction of microbial counts in salted shredded Korean cabbage at various NaCl and GSE concentrations and fixed MD concentration (5%) and salting time (5 hr).

GSE, grape seed extract; MD, maltodextrin.
(a), Total aerobic bacteria; (b), yeast/molds.

Changes in sensory qualities of salted shredded Korean cabbage

We calculated R^2 values to evaluate the goodness of fit of the quadratic model for sensory qualities of salted shredded Korean cabbage processed under different salting conditions to the experimental results (Table 3). The ANOVA showed that the resultant polynomial model adequately fit the experimental data, with R^2 coefficients of 0.960, 0.975, and 0.984 for taste, texture, and overall acceptability, respectively. These results indicate that the quadratic model accounts for >95% of the variation in the experimental data. In addition, the R^2_{adj} values for taste, texture, and overall acceptability were 0.934, 0.955, and 0.970, respectively, indicating a good fit for the model.

The coefficients of the regression equation describing changes in the sensory quality of salted shredded Korean cabbage under different salting conditions are shown in Table 3. Sensory qualities including taste, texture, and overall acceptability of the cabbage were primarily affected by the linear terms of NaCl concentration and salting time ($p<0.01$ or $p<0.001$); moreover, the interaction between these two parameters was significant ($p<0.001$). The quadratic terms of NaCl concentration also had a significant negative effect on sensory quality ($p<0.001$), whereas salting time and MD and GSE concentrations did not affect these responses. It has been reported that hyper-salting negatively affects the sensory quality of salted Korean cabbage, although it was more effective in reducing salting time (4). Similar observations were made in the present investigation. MD and GSE supplementation had no significant effects on the taste, texture, or overall acceptability of the cabbage ($p>0.05$).

Response surface plots for the improvement of sensory quality of salted shredded Korean cabbage processed under various salting conditions revealed that sensory scores for taste, texture, and overall acceptability decreased when the NaCl concentration was >10% (Fig. 2a-c). In contrast, MD and GSE concentrations did not affect the sensory quality

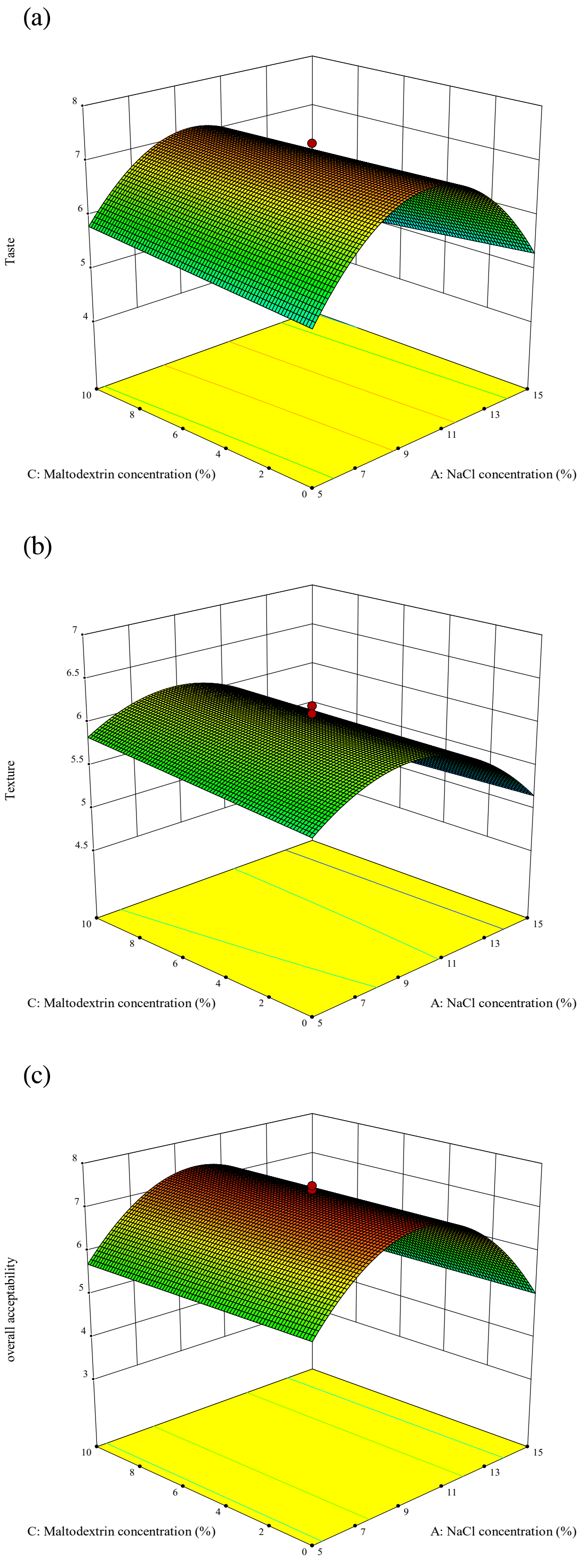

Fig. 2. Response surface plots for changes in sensory qualities of salted shredded Korean cabbage at various NaCl and MD concentrations and fixed salting time (5 hr) and GSE concentration (150 ppm).

MD, maltodextrin; GSE, grape seed extract.
(a), Taste; (b), texture; (c), overall acceptability.

(p>0.05). It should thus be noted that binary or ternary salting solutions are capable of reducing the amount of preexisting microorganisms without undermining product quality.

Being an osmotic agent, salt suppresses oxidative or non-enzymatic browning and surface shrinkage, providing the driving force for mass transfer as well as a salty taste (31). In a preliminary study, >500 ppm GSE in the salting solution caused discoloration of the cabbage surface because of chlorophyll degradation. We therefore used GSE concentrations <300 ppm based on another report in which GSE did not affect the color of lettuce leaves and jalapeno peppers during storage (32). We expect the combination of MD and GSE in this study to have dual effects on microbial inactivation and salting time with minimal negative effects on the sensory quality of the product.

Changes in salt characteristics of salted shredded Korean cabbage

Weight loss is the most critical attribute for directly evaluating the degree of dehydration of Korean cabbage during the salting process. Additionally, salt content is an important determinant of gustatory appeal.

The ANOVA showed that the quadratic polynomial model adequately fit the experimental data, with R^2=0.981 and 0.992 and R^2_{adj}=0.958 and 0.989 for changes in weight loss and salt content, respectively, indicating good agreement between the experimental and predicted values.

The regression coefficients in Table 3 show that the linear terms of NaCl concentration, salting time, and MD concentration had significant positive effects on reductions in weight loss in salted shredded Korean cabbage (p<0.001). NaCl concentration and salting time had significant positive effects (p<0.001), whereas MD concentration had a significant negative effect (p<0.001) on salt content. In contrast, GSE concentration did not affect changes in weight loss and salt content. The interaction of NaCl and MD concentrations significantly influenced the reduction in weight loss (p<0.05). Notably, the effect of NaCl concentration and salting time on weight loss during the salting process increased as the MD concentration increased. The quadratic term of the four independent variables did not significantly affect the changes in weight loss and salt content (p>0.05).

Response surface plots were generated to visualize the combined effects of the four independent variables on changes in weight loss (Fig. 3a) and salt content (Fig. 3b). The samples were shredded Korean cabbage treated with different concentrations of NaCl and MD at a fixed salting time of

5 hr and GSE concentration of 150 ppm. Weight loss increased as a function of NaCl and MD concentrations. Salt penetrates into the cabbage via a dialysis mechanism, whereas water diffuses out by osmotic pressure. The rates of salt uptake and water release depend on the difference between NaCl and MD concentrations in the salting solution as well as salting time. The salt content of the cabbage increased with the concentration of NaCl used during salting; for instance, it was higher in cabbage salted with 15% brine as compared to 5 or 10% brine in the first 2~5 hr of the process. This effect can be explained by the difference in salt concentration inside and outside the cabbage, which leads to a higher penetration rate of salt into the cabbage during hyper-salting with 15% brine. Additionally, use of 10% MD as a supplementary salting medium reduced the rate of salt uptake.

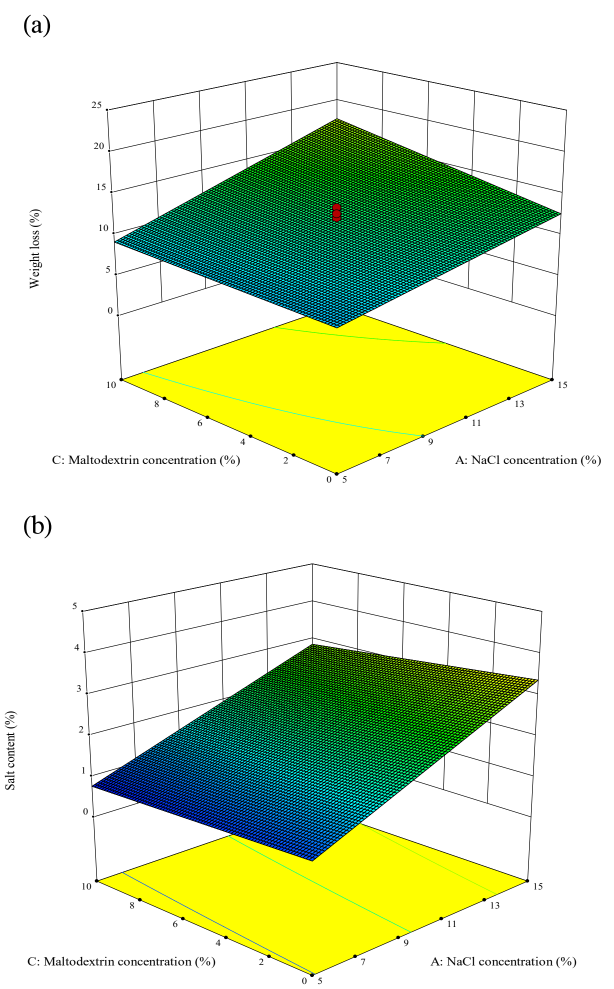

Fig. 3. Response surface plots for changes in salting characteristics of salted shredded Korean cabbage at various NaCl and MD concentrations and fixed salting time (5 hr) and GSE concentration (150 ppm).

MD, maltodextrin; GSE, grape seed extract.
(a), Weight loss; (b), salt content.

Thus, the salt content of shredded Korean cabbage can be controlled by MD supplementation of the salting solution. In addition, 10% MD supplementation during salting increased weight loss as compared to cabbage salted with brine but without MD for up to 5 hr.

The osmotic pressure gradient that drives mass transfer depends on the concentration of the salting solution (31). Low-molecular-weight osmotic agents such as salt can readily penetrate into cabbage. The moisture loss in onion and tomato samples subjected to osmotic dehydration in salt solution was reported to be higher than that in sucrose solution. This is because of the passage of the smaller salt molecules through cell membranes and the resultant pressure gradient in the cytoplasm and vacuoles, which increases water loss from the cells (33). In addition, maximum dehydration of cherry tomatoes was achieved using a mixed solution of salt and sucrose that increased the concentration gradient (34). Similarly, MD has a higher molecular weight than other frequently used osmotic agents (e.g., salt, glucose, sucrose, and maltose) (31) and thus does not penetrate the cell membrane, which likely led to its enhancement of dehydration in the present study.

Optimization of salting conditions

We optimized the salting conditions by analyzing numerical simulations of the best combination of NaCl, MD, and GSE concentration and salting time. The optimal conditions were those that minimized total aerobic bacteria and yeast/mold counts, with weight loss in the range of 15~23%, salt content in the range of 1.5~2.0%, and sensory quality scores >6. Based on this analysis, the optimum values were: an NaCl concentration of 10.09~10.32%, MD concentration of 9.45~10.00%, GSE concentration of 234~300 ppm, and salting time of 5.68~5.94 hr.

In summary, this study established the ideal salting conditions with NaCl, MD, and GSE for improving the microbiological safety and quality of salted shredded Korean cabbage used for kimchi production. This new formulation involves no additional expense or specialized facilities, as MD and GSE are simply added during the salting process. In addition, the use of MD shortens the salting time and consequently decreases weight loss. Large-scale experiments are needed to verify that the optimal conditions determined here can be applied to commercial kimchi manufacturing.

요 약

본 연구는 절단 절임배추의 미생물학적 안전성과 품질 확보를 위해 maltodextrin(MD)과 grape seed extract(GSE)를 첨가한 새로운 절임 조건을 개발하고자 수행되었다. 반응표면분석법을 이용하여 분석한 결과, 10.09~10.32% NaCl, 9.45~10.00% MD와 234~300 ppm GSE를 병합한 절임염수와 5.68~5.94 hr의 절임시간이 절단 배추의 최적 절임 조건으로 나타났다. 이 절임 조건하에서 절단 배추의 총호기성 세균과 효모 및 곰팡이 수는 3.33과 1.45 log CFU/g까지 각각 감소한 반면 관능적 품질인 맛, 조직감과 종합적 기호도는 6점 이상의 높은 점수를 유지하였다. 또한 이 절임 조건은 절임 중 적절한 배추의 중량감소율인 15~23%와 절임배추의 최적 염도인 1.5~2.0%를 만족하는 것으로 나타났다. 따라서 본 연구결과, MD와 GSE가 첨가된 절임염수는 배추의 위해미생물 감소뿐만 아니라 품질유지에 효과를 보여줌으로써 김치 제조를 위한 배추의 절임공정에 활용할 수 있는 가능성을 제시하였다.

Acknowledgement

This research was supported by the WIKIM Institutional Research Program (KE1602-1) through the World Institute of Kimchi funded by the Ministry of Science, ICT, and Future Planning, Republic of Korea.

References

1. Ji YS, Kim HN, Park HJ, Lee JE, Lee HJ, Shin HK, Kim BJ, Franz CMAP, Holzapfel WH (2013) Functionality and safety of lactic bacterial strains from Korean kimchi. Food Control, 31, 467-473
2. Kang SJ, Kim SJ, Kim SH, Lee JH, Park SY, Ha SD (2016) Comparison of the murine norovirus-1 inactivation in cabbage kimchi with two different salinities during storage. Food Res Int, 84, 96-101
3. Kim NH, Jang SH, Kim SH, Lee HJ, Kim YH, Ryu JH, Rhee MS (2015) Use of phytic acid and hyper-salting to eliminate *Escherichia coli* O157:H7 from napa cabbage for kimchi production in a commercial plant. Int J Food Microbiol, 214, 24-30
4. Ryu JP, Yang JH, Chung YB, Lee SI, Han ES (2014) Quality characteristics of *baechu-kimchi* salted at high salt concentration for a short time. J Korean Soc Food Sci Nutr, 43, 1913-1919
5. Choi EJ, Chung YB, Han AR, Chun HH (2015) Combined effects of sanitizer mixture and antimicrobial ice for improving microbial quality of salted Chinese cabbage during low temperature storage. J Korean Soc Food Sci Nutr, 44, 1715-1724
6. Cho SH, Kim J, Oh KH, Hu JK, Seo J, Oh SS, Hur MJ, Choi YH, Youn SK, Chung GT, Choe YJ (2014) Outbreak of enterotoxigenic *Escherichia coli* O169 enteritis in school-children associated with consumption of kimchi, Republic of Korea, 2012. Epidemiol Infect, 142, 616-623
7. Park JG, Kim JH, Park JN, Kim YD, Kim WG, Lee JW, Hwang HJ, Byun MW (2008) The effect of irradiation temperature on the quality improvement of *Kimchi*, Korean fermented vegetables, for its shelf stability. Radiat Phys Chem, 77, 497-502
8. Jeong JW, Park SS, Lim JH, Park KJ, Kim BK, Sung JM (2011) Quality characteristics of Chinese cabbage with different salting conditions using electrolyzed water. J Korean Soc Food Sci Nutr, 40, 1743-1749
9. Kim JH, Lee YK, Yang JY (2011) Change of harmful microorganisms in picking process of salted cabbage according to salting and washing conditions. J Food Hyg Safety, 26, 417-423
10. Lee KH (2008) Effect of ozone treatment for sanitation of Chinese cabbage and salted Chinese cabbage. J Korean Soc Food Sci Nutr, 37, 90-96
11. Bermúdez-Aguirre D, Barbosa-Cánovas GV (2013) Disinfection of selected vegetables under nonthermal treatments: Chlorine, acid citric, ultraviolet light and ozone. Food Control, 29, 82-90
12. Gomez-Lopez VM, Lannoo AS, Gil MI, Allende A (2014) Minimum free chlorine residual level required for the inactivation of *Escherichia coli* O157:H7 and trihalomethane generation during dynamic washing of fresh-cut spinach. Food Control, 42, 132-138
13. Kao TT, Tu HC, Chang WN, Chen BH, Shi YY, Chang TC, Fu TF (2010) Grape seed extract inhibits the growth and pathogenicity of *Staphylococcus aureus* by interfering with dihydrofolate reductase activity and folate-mediated one-carbon metabolism. Int J Food Microbiol, 141, 17-27
14. Nowshehri JA, Bhat ZA, Shah MY (2015) Blessings in disguise: Bio-functional benefits of grape seed extracts. Food Res Int, 77, 333-348
15. Lau DW, King AJ (2003) Pre and post-mortem use of grape seed extract in dark poultry meat to inhibit

development of thiobarbituric acid reactive substances. J Agric Food Chem, 51, 1602-1607

16. Perumalla AVS, Hettiarachchy NS (2011) Green tea and grape seed extracts-potential applications in food safety and quality. Food Res Int, 44, 827-839
17. Molva C, Baysal AH (2015) Antimicrobial activity of grape seed extract on *Alicyclobacillus acidoterrestris* DSM 3922 vegetative cells and spores in apple juice. LWT-Food Sci Technol, 60, 238-245
18. Kim JH, Park KY, Choi HS, Yang JY (2010) Quality evaluation of conventional salted cabbages. Korean J Food Nutr, 23, 659-663
19. Kim MH, Kim MK, Yu MS, Song YB, Seo WJ, Song KB (2009) Dehydration of sliced ginger using maltodextrin and comparison with hot-air dried and freeze-dried ginger. Korean J Food Sci Technol, 41, 146-150
20. Lenart A, Flink JM (1984) Osmotic concentration of potato. Criteria for the end point of the osmotic process. Int J Food Sci Technol, 19, 45-63
21. Cho MJ, Kim HJ (2015) Effect of the dextrose equivalent of maltodextrin on the quality characteristics of Jeju purple sweet potato (*Ipomoea batatas* L.) during molecular press dehydration. Korean J Food Sci Technol, 47, 744-750
22. Mohammadi R, Mohammadifar MA, Mortazavian AM, Rouhi M, Ghasemi JB, Delshadian Z (2016) Extraction optimization of pepsin-soluble collagen from eggshell membrane by response surface methodology (RSM). Food Chem, 190, 186-193
23. Sumic Z, Vakula A, Tepic A, Cakarevic J, Vitas J, Pavlic B (2016) Modeling and optimization of red currants vacuum drying process by response surface methodology (RSM). Food Chem, 203, 465-475
24. da Costa Ribeiro AS, Aguiar-Oliveira E, Maldonado RR (2016) Optimization of osmotic dehydration of pear followed by conventional drying and their sensory quality. LWT-Food Sci Technol, 72, 407-415
25. Izadiyan P, Hemmateenejad B (2016) Multi-response optimization of factors affecting ultrasonic assisted extraction from Iranian basil using central composite design. Food Chem, 190, 864-870
26. Serio A, Chaves-Lopez C, Martuscelli M, Mazzarrino G, Mattia CD, Paparella A (2014) Application of Central Composite Design to evaluate the antilisterial activity of hydro-alcohol berry extract of *Myrtus communis* L. LWT-Food Sci Technol, 58, 116-123
27. Anastasio A, Smaldone G, Cacace D, Marrone R, Lo Voi A, Santoro M, Cringoli G, Pozio E (2016) Inactivation of *Anisakis pegreffii* larvae in anchovies (*Engraulis encrasicolus*) by salting and quality assessment of finished product. Food Control, 64, 115-119
28. Jayaprakasha GK, Selvi T, Sakariah KK (2003) Antibacterial and antioxidant activities of grape (*Vitis vinifera*) seed extracts. Food Res Int, 36, 117-122
29. Meireles A, Giaouris E, Simoes M (2016) Alternative disinfection methods to chlorine for use in the fresh-cut industry. Food Res Int, 82, 71-85
30. Choi JD, Seo IW, Cho SH (1990) Studies on the antimicrobial activity of grapefruit seed extract. J Korean Fish Soc, 23, 297-302
31. Ahmed I, Quzi IM, Jamal S (2016) Developments in osmotic dehydration technique for the preservation of fruits and vegetables. Innovative Food Sci Emerging Technol, 34, 29-43
32. Su X, D'Souza DH (2013) Grape seed extract for foodborne virus reduction on produce. Food Microbiol, 34, 1-6
33. Konopacka D, Jesionkowska K, Klewicki R, Bonazzi C (2009) The effect of different osmotic agents on the sensory perception of osmo-treated dried fruit. J Hortic Sci Biotechnol, 80-84
34. Derossi A, Severini C, Del Mastro A, De Pilli T (2015) Study and optimization of osmotic dehydration of cherry tomatoes in complex solution by response surface methodology and desirability approach. LWT-Food Sci Technol, 60, 641-648