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Development and Application of Multi-Function Valve to Solve Major Problems of Expansion and Off-Odor Leakage in the Packaging of Kimchi

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Abstract The one-way gas valve developed in this study was designed to prevent the breakage of packages from increased internal pressure, which is a problem in packaged Kimchi, and simultaneously reduce the outflow of the off-odor release. The effect of the one-way gas valve on the headspace atmospheric compositions was investigated in the packaging system. The changes of atmospheric compositions and quality factors of Kimchi, such as CO_2 accumulation, pH, titratable acidity, and salinity, were measured during a 4-week storage period at 4°C. The Kimchi package with the one-way gas valve dramatically reduced pressure build-up in the pouch by allowing the controlled flow of gas to the atmosphere. In addition, the package design allows the possibility of controlling the gas generated from Kimchi by adjusting the viscosity of the open pressure control oil. The one-way gas valve did not affect the sensory characteristics of Kimchi products during the storage period. Furthermore, the deodorizing capability of the activated carbon contained in the one-way gas valve effectively reduced the off-odor of Kimchi products released along with carbon dioxide. The novel one-way gas valve is considered to be an active packaging system that can solve major problems of expansion and off-odor leakage in the packaging of Kimchi.

Keywords One-way gas valve, Kimchi packaging, CO_2 emissions, Deodorization

Introduction

Kimchi is Korea's representative traditional fermented vegetable food. Kimchi cabbage and Korean radish are the main ingredients of the most popular type of Kimchi. Sub-ingredients include fresh onion, ginger, garlic, dried cayenne pepper powder, and fermented fish sauce[1)]. The ingredients of Kimchi are trimmed, cut, salted, and seasoned before fermentation. Fermented fish sauce provides enzymes and flavor substances for the fermentation. Salt, garlic, ginger, onion, and dried cayenne pepper are important in controlling the type of microflora in Kimchi.[2-4)] Kimchi has an optimal taste when properly fermented to a pH of approximately 4.2 with 0.6-0.8% (as lactic acid) titratable acidity. The taste differs from that of the well-known western vegetable product, sauerkraut.[1,5)]

The best characteristics of Kimchi are a result of LAB fermentation using salted vegetables (such as Kimchi cabbage or Korean radish). The various fermentation metabolites that are produced include carbon dioxide (CO_2), organic acids (lactic acid), vitamins, volatile flavoring compounds, and prebiotic factors. Microbial distribution/population during fermentation directly influences Kimchi quality attributes, such as metabolites (CO_2, and organic acid), taste, and nutritional and organoleptic properties of Kimchi products.[6)] Kimchi quality is also reportedly influenced by fermentation temperature, raw materials (vegetable type, harvesting area, season, and cultivar), salt concentration, ingredients, pH, air exposure, and starter culture conditions. *Leuconostoc mesenteroides*, *Weissella koreensis*, and *Lactobacillus plantarum* are the main LAB for Kimchi fermentation. These LAB are predominant in the early (*Leuconostoc mesenteroides*), middle (*Lactobacillus plantarum*), and later (*Weissella koreensis*) phase of Kimchi fermentation, respectively.[7-10)] During the fermentation period, the pH is decreased while CO_2 accumulation, acidity, and populations of bacteria are increased. In addition, sulfur-containing volatile odor components produce the characteristic pungent smell of Kimchi products. These include methyl allyl sulfide, dimethyl disulfide, diallyl disulfide, and methyl allyl trisulfide, and are produced by sub-ingredients of Kimchi that include garlic, ginger, onion, and green onion. Generally, the intensity of off-odors is enhanced by the metabolites produced as Kimchi fermentation progresses.[11-13)]

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The primary roles of Kimchi packaging are to easily contain and distribute Kimchi, to protect Kimchi products from the external environment and damage, to extend the shelf life, to retain the beneficial effects of fermentation, to maintain/increase the quality and safety of Kimchi, and to provide consumers with ingredient and nutritional information.[14] The most commonly used Kimchi packaging materials for domestic consumption and export are plastic film pouches, rigid plastic containers, glass bottles, and cans.[15] Unlike conventional foods, commercial fresh Kimchi products maintain continuous lactic acid fermentation during storage and distribution. The packaging of fresh Kimchi is complicated by the typical lack of pasteurization, and the presence of living LAB. The continuous fermentation brings about various microbiological, biochemical, and physical changes during the storage and circulation of the packaged Kimchi products, which include the growth of LAB, reduction of pH, and softening of vegetable tissue. In particular, LAB fermentation proceeds continuously in packaged Kimchi resulting in the evolution of CO_2, which causes pressure build-up in rigid packages and volume expansion in flexible Kimchi packages.[16-18] The breakage of Kimchi package by CO_2 accumulation can cause problems such as leakage of odor and deterioration of quality aspects including flavor. Leakage reduces the shelf life of Kimchi and lowers consumer preference and the commercial viability of Kimchi products. Therefore, the foremost priority of Kimchi packages is to prevent the damage caused by CO_2 accumulation. This priority has prompted the exploration of various processing and active packaging materials and systems, such as canning, bottling, pasteurization, addition of preservatives, use of food additives, pinhole packaging, use of laser-etched pouches, and use of a sachet containing CO_2 as an absorber. However, only a few methods are used commercially.[19-23] Moreover, gas-absorbent materials, such as KOH, NaOH, $Ca(OH)_2$, $MgCl_2$, and $CaCl_2$, reportedly prevent package expansion and extend the shelf life of kimchi. These materials tend to delay the pH decrease of Kimchi products, but deteriorate the quality of Kimchi because of the inability to maintain proper CO_2 levels in the packaging. While a packaging container enabling the discharge of CO_2 has been a recent innovation in Kimchi packaging, the problem of the leakage of the Kimchi odor from packaging is unresolved.

The study was aimed to develop an active packaging system for Kimchi capable of reducing the leakage of undesirable odor produced by the fermented Kimchi while maintaining the optimal pressure level by controlling CO_2 emission from packaged Kimchi. To evaluate the influence of the developed packaging system on the quality of Kimchi, the changes of the quality factors of pH, titratable acidity, and salinity were determined. Changes in the sensory characteristics of Kimchi products and deodorizing function of Kimchi packaging valve were confirmed by sensory evaluation.

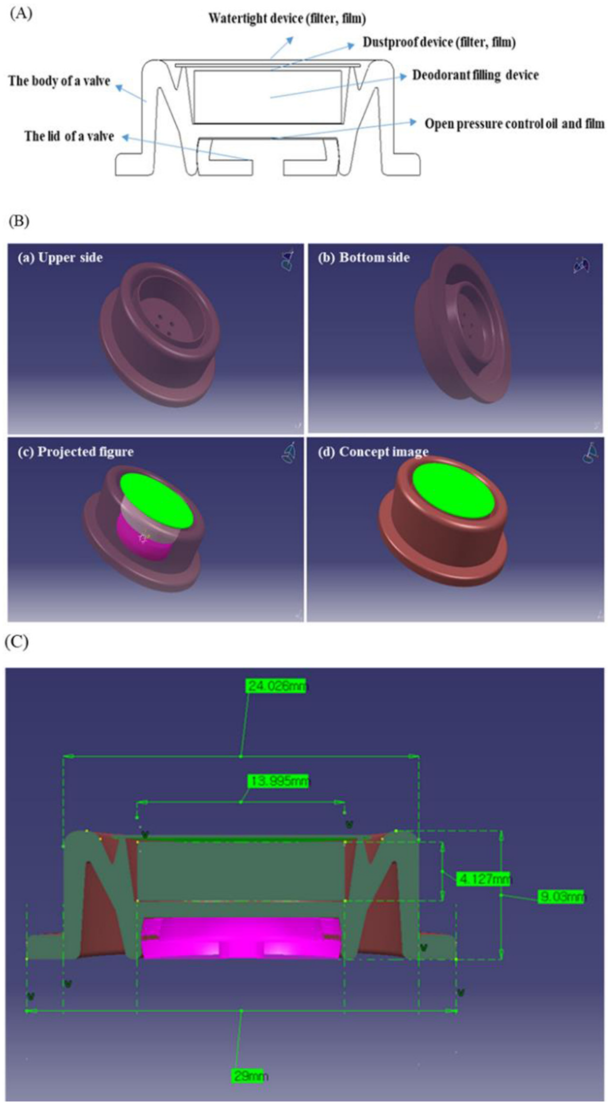

Fig. 1. Concept design (A), 3D rendering image (B), and dimension (C) of one-way gas valve.

Materials and Methods

1. Description of active packaging system with one-way gas valve for fermented Kimchi

As shown in Fig. 1A, the one-way gas valve developed in this study is composed of a watertight and dustproof device, body, cover, deodorant filling device, open pressure control oil, and film. The prototype of one-way gas valve was manufactured by FRESONE Co. Ltd (Yongin, South Korea).

The one-way gas valve is designed to prevent the damage (expansion and leakage) of the package by excessive production of CO_2 from fermented Kimchi products during distribution and storage and to reduce the off-odor of Kimchi leaking out of the package. It is also designed to maintain the

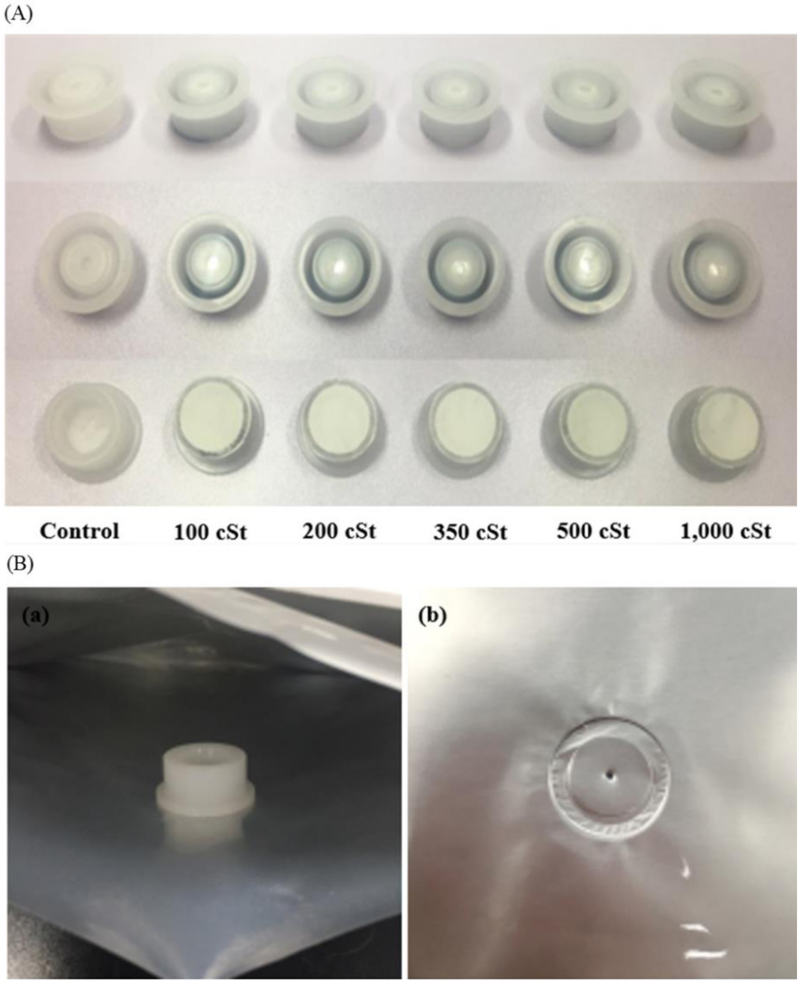

Fig. 2. The prototype of the one-way gas valve (A) and Kimchi pouch with the one-way gas valve (B): (a) interior and (b) exterior of the packaging.

unique carbonic taste of Kimchi and to prevent external air from entering the package.

As shown in Fig. 1B, C, and 2 the valve was designed to effectively discharge the gas generated inside to package to the surrounding air and to maintain the desirable sensory and physicochemical properties of the Kimchi. The body and cover of the one-way gas valve are made of polyethylene (PE) and the internal air is exhausted through the four holes in the body of the valve (Fig. 1B). An installed dustproof filter prevents the external loss of the activated carbon powder that is used as a deodorant. Also, a waterproof filter prevents deterioration in the performance of the one-way gas valve due to contact with the Kimchi soup. Oil (XIAMETER^{TM} PMS-200 SILICONE FLUID 500 cSt; dimethyl siloxane, trimethylsiloxy-terminated) is used to control the open pressure of the one-way gas valve. The degree of internal gas discharge can be controlled by adjusting the viscosity of the oil. The dimension of Kimchi pouch used in this experiment was 290 mm width, and 230 mm height. One kg of Kimchi was added to the pouch and stored at 4^{o}C for 4 weeks.

2. Measurement of headspace pressure and atmospheric composition in packaging

The headspace pressure of the pouch was measured using a headspace pressure gauge (UTK-P5000; Ultra Tec, Seoul, South Korea). The pressure represents the atmospheric pressure relative to 1.011 atm. The headspace atmospheric composition in the package was determined using a headspace gas analyzer (GS3 Micro; Systech Illinois Instruments Inc., Johnsburg, IL, USA). The gas composition of the atmosphere was measured based on 20.9% oxygen, 0.3% CO_2, and 78.8% nitrogen. Each sample was analyzed in three replicates.

3. Salinity, pH, and titratable acidity changes

Salinity was titrated with 0.02 N $AgNO_3$ solution after mixing 10 mL Kimchi filtrate and 1 mL of 2% potassium chromate. The pH of homogenized Kimchi was determined using a pH meter (TitroLine Easy; SI Analytics GmbH, Mainz, Germany) and the mean of three measurements is presented. Titratable acidity of Kimchi filtrates are expressed as percent (%) of total acid by titrating 10 mL of Kimchi juice with 0.1 N NaOH to a pH 8.3. Titratable acidity was calculated on the basis of lactic acid and expressed as the % total acid. All experiments involved three replicates. Results are presented as the mean value of three measurements for each sample.

4. Sensory evaluations

A trained 12-member panel consisting of researchers from the Department of World Institute of Kimchi in Korea evaluated the sensory characteristics of the Kimchi. Kimchi samples stored at 4°C for 4 weeks using different valve types were randomly coded and evaluated. The change of sensory characteristics (product-specific taste, color, flavor, texture, and overall preference) of the Kimchi stored in packages using the various valve types was evaluated by a 9-point hedonic scale. The lowest and highest scores for taste, color, flavor, texture, overall preference, and odor-intensity were 1 and 9, respectively.

5. Statistical analysis

All experiments were performed in triplicate and the data are presented as means±standard deviation of three replicate determinations. Tests for statistical significance were performed using IBM SPSS software Version 19 (IBM SPSS Statistics Inc., Chicago, IL, USA). The significance of differences of average values was determined using Duncan's multiple range tests (p<0.05).

Results and Discussion

1. Changes of headspace pressure and atmospheric compositions in pouches with and without a one-way gas valve

Excessive production of CO_2 by heterofermentative LAB during storage and distribution can cause breakage of Kimchi packages due to volume expansion and leakage of Kimchi soup. To solve these problems, many studies have explored the use of CO_2 adsorbents based on $CaCl_2$, $MgCl_2$, and Na_2CO_3, packaging with high-permeability film, gas-permeable packaging using micro-pore processing, and degassing valves.[19-21,24-26] Changes of headspace pressure and atmospheric compositions (O_2, and CO_2) in kimchi packages stored for 0, 2, and 4 weeks are shown in Table 1. In Kimchi packages without a one-way gas valve, headspace pressure increased (from 0.115 to 0.600) as did CO_2 accumulation (from 8.23 to 81.50%) were

Table 1. Comparative analysis of the atmospheric compositions and quality factors of Kimchi packages with the one-way valve between different open pressure levels

Attribute		Storage time (weeks)	One-way gas valve open pressure (Centistock, cSt)					
			Without valve	0	100	200	350	500
Package atmosphere	Pressure	0	0.115±0.004^{c}	0.109±0.002^{d}	0.107±0.002^{de}	0.104±0.002^{ef}	0.102±0.001^{f}	0.104±0.001^{ef}
		2	0.173±0.006^{b}	0.044±0.001^{j}	0.056±0.008^{hi}	0.052±0.002^{i}	0.059±0.001^{h}	0.066±0.004^{g}
		4	0.600±0.011^{a}	0.022±0.002^{lm}	0.020±0.003^{m}	0.026±0.004^{kl}	0.026±0.002^{kl}	0.027±0.005^{k}
	O_2 (%)	0	15.35±1.67^{c}	18.60±0.17^{a}	17.52±0.10^{ab}	17.15±1.12^{b}	17.30±0.06^{b}	16.90±0.54^{b}
		2	0.00±0.00^{h}	15.28±0.12^{c}	9.77±0.41^{f}	11.00±0.85^{e}	6.48±0.14^{g}	5.44±2.92^{g}
		4	0.00±0.00^{h}	14.67±1.21^{cd}	13.67±0.31^{d}	10.17±1.02^{ef}	10.23±0.12^{ef}	9.17±0.17^{f}
	CO_2 (%)	0	8.23±1.64^{i}	2.73±0.21^{j}	4.87±0.10^{ij}	5.13±1.43^{ij}	4.75±0.08^{ij}	5.43±0.80^{ij}
		2	79.30±0.37^{a}	17.78±0.21^{h}	41.40±2.23^{de}	34.25±4.16^{f}	53.90±2.74^{c}	58.48±7.43^{b}
		4	81.50±1.95^{a}	21.73±3.31^{gh}	24.67±1.53^{g}	37.92±3.45^{ef}	37.93±0.49^{ef}	42.38±1.15^{c}
Salinity (%)		0	1.83±0.07^{def}	1.91±0.03^{bcd}	1.74±0.03^{h}	1.85±0.03^{def}	1.89±0.03^{cde}	1.77±0.03^{fgh}
		2	1.77±0.03^{fgh}	1.89±0.03^{cde}	1.95±0.03^{abc}	1.85±0.03^{def}	1.97±0.03^{ab}	1.95±0.03^{abc}
		4	1.81±0.10^{efg}	1.76±0.01^{gh}	1.89±0.03^{cde}	2.01±0.03^{a}	1.85±0.03^{def}	1.95±0.03^{abc}
pH		0	5.71±0.03^{ab}	5.67±0.03^{b}	5.72±0.06^{ab}	5.68±0.02^{ab}	5.74±0.01^{a}	5.69±0.05^{ab}
		2	4.34±0.06^{c}	4.26±0.02^{de}	4.26±0.02^{de}	4.23±0.03^{e}	4.30±0.04^{ce}	4.27±0.01^{de}
		4	4.24±0.02^{de}	4.12±0.06^{f}	4.16±0.03^{f}	4.16±0.02^{f}	4.10±0.04^{f}	4.10±0.05^{f}
Titratable acidity (%)		0	0.435±0.001^{m}	0.458±0.006^{l}	0.437±0.005^{m}	0.498±0.005^{i}	0.479±0.019^{jk}	0.458±0.010^{l}
		2	0.948±0.005^{i}	1.106±0.008^{f}	1.112±0.006^{f}	1.084±0.003^{g}	1.041±0.004^{h}	1.113±0.020^{f}
		4	1.136±0.009^{e}	1.325±0.011^{c}	1.324±0.013^{c}	1.371±0.005^{a}	1.349±0.007^{b}	1.260±0.004^{d}

*Different letters indicate significant difference at the level of p<0.05

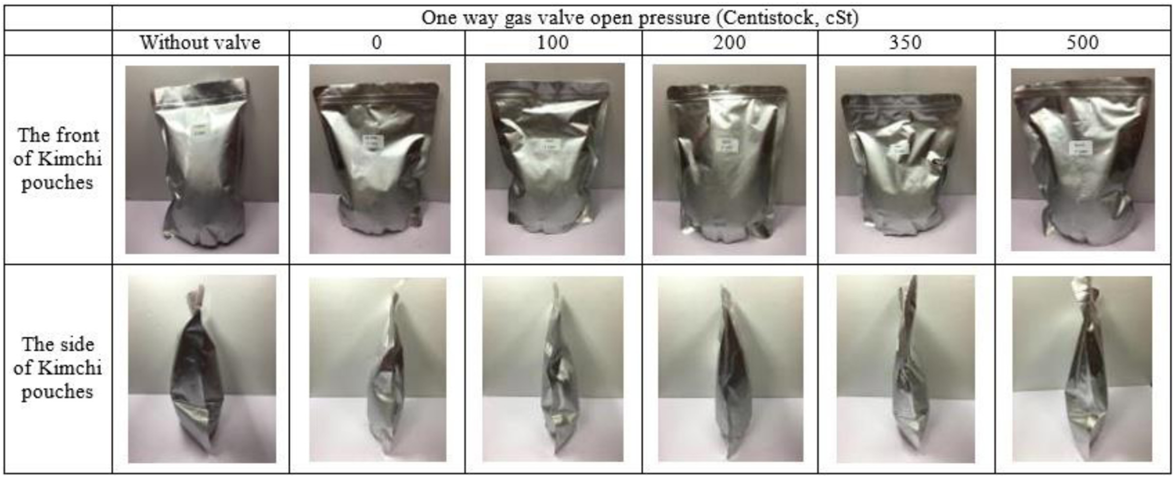

Fig. 3. Differences in volume expansion of Kimchi packages with and without the one-way valve at different open pressure levels at 4 weeks.

increased. Conversely, oxygen concentration decreased from 15.35 to 0.00% during the 4-week storage time. In the Kimchi packages equipped with a one-way gas valve, which allowed the passage for limited gas flow, the headspace pressure of the Kimchi package was reduced, but there were no significant differences according to the viscosity of the oil. The one-way gas valve effectively reduced CO_2 accumulation and volume expansion in the Kimchi packages (Table 1 and Fig. 3). Moreover, th CO_2 accumulation significantly increased in all packages from 21.73 to 42.38% as the viscosity of oil increased from 0 cSt to 500 cSt, while the oxygen concentration tended to decrease as the viscosity of oil increased. The results confirmed that the one-way gas valve could reduce the headspace pressure by controlling CO_2 emissions. In addition, it is considered that sensory aspects of Kimchi, such as carbonic taste and flavor, could be controlled by adjusting the viscosity of the valve oil.

2. Changes in pH, salinity, and titratable acidity of Kimchi during storage

In the typical microbial changes during Kimchi fermentation, LAB increase, whereas aerobes and pathogens decrease due to the absence of air, salt content, and acid formed during fermentation. Kimchi fermentation produces lactic acid, acetic acid, CO_2, and ethanol as metabolites from saccharides using various metabolic pathways. The initial stage of Kimchi fermentation leads to a rapid decrease of pH accompanied by a decrease of reducing sugars. The next stage is a gradual drop in pH (i.e. increased acidity). The final stage features no changes in pH, and acidity.[3] The pH and acidity of optimally fermented Kimchi are 4.2 to 4.5 and 0.6 to 0.8%, respectively. Presently, the pH decreased from 5.74 to 4.10 during storage in all samples (Table 1). The pH of Kimchi stored in packages equipped with the one-way gas valve was similar to that of control Kimchi stored in packages without the valve. On the other hand, the titratable acidity of Kimchi increased continuously during the storage period, and was approximately 0.2% higher in Kimchi stored in packages with the one-way gas valve than in the control Kimchi packages.

3. Sensory evaluation according to one-way gas valve types

Fresh Kimchi is not a fully fermented product and provides the unique flavor and texture that is typical of vegetable salad. During the fermentation period, the typical organoleptic qualities of flavor, taste, color, and texture of Kimchi products are formed. Properly fermented Kimchi has a unique sourness, is somewhat sweet, and has a characteristic texture, carbonic taste, and flavor. Generally, optimally ripened Kimchi displays a pH of approximately 4.2 with 0.6-0.8% acidity. The atmospheric composition, storage temperature, and salt concentration of Kimchi products affect the distribution/population/growth of LAB, as well as the sensory characteristics of Kimchi. Especially, the fermentation temperature is one of the most important factors influencing Kimchi fermentation, because it affects the dominance of LAB such as *Leuconostoc* sp., and *Lactobacillus* sp., which predominate in Kimchi fermentation.[27] In this study, the sensory evaluations were performed to confirm the change of sensory characteristics (flavor, taste, color, and texture) of Kimchi products stored in a pouch equipped with the one-way gas valve. Kimchi products were stored at 4°C for 4 weeks. For sensory evaluation, high scores of taste and flavor were obtained for Kimchi stored in packages with the one-way gas valve; these scores corresponded to the changes of CO_2 concentration in the pouches (Table 2). The overall preference for Kimchi was not affected by the presence

Table 2. Sensory evaluation according to the one-way gas valve types during storage for 4 weeks at 4°C

Attribute	Storage time (weeks)	One-way gas valve open pressure (Centistock, cSt)					
		Without valve	0	100	200	350	500
Flavor	0	6.08 ± 1.00^{a}	6.00 ± 1.13^{a}	6.00 ± 1.28^{a}	6.08 ± 1.00^{a}	5.83 ± 1.00^{ab}	5.75 ± 1.29^{abc}
	2	5.33 ± 1.30^{abcd}	4.66 ± 1.30^{bcde}	5.08 ± 1.31^{abcde}	5.50 ± 1.31^{abcd}	5.08 ± 1.68^{abcde}	5.08 ± 1.31^{abcde}
	4	4.00 ± 1.41^{e}	4.25 ± 1.36^{de}	4.75 ± 1.60^{abcde}	4.50 ± 1.31^{cde}	4.41 ± 2.11^{de}	4.75 ± 1.48^{abcde}
Taste	0	5.50 ± 1.92^{a}	5.50 ± 1.30^{a}	5.10 ± 1.56^{a}	5.70 ± 1.28^{a}	5.40 ± 1.43^{a}	5.70 ± 1.35^{a}
	2	4.83 ± 1.85^{a}	4.42 ± 1.68^{a}	5.50 ± 1.24^{a}	4.25 ± 2.45^{a}	5.08 ± 1.44^{a}	5.08 ± 1.88^{a}
	4	3.91 ± 1.93^{a}	4.18 ± 1.44^{a}	4.82 ± 1.42^{a}	4.27 ± 2.29^{a}	4.18 ± 1.75^{a}	5.00 ± 1.82^{a}
Color	0	5.00 ± 1.60^{ab}	5.08 ± 1.24^{a}	5.00 ± 1.13^{ab}	5.00 ± 1.41^{ab}	4.75 ± 0.97^{abc}	5.08 ± 1.24^{a}
	2	4.67 ± 1.56^{abcd}	4.75 ± 1.06^{abc}	4.33 ± 1.72^{abcd}	4.42 ± 1.62^{abcd}	4.17 ± 1.53^{abcd}	4.17 ± 1.64^{abcd}
	4	3.75 ± 1.14^{bcd}	3.50 ± 0.90^{cd}	3.83 ± 1.70^{abcd}	3.42 ± 0.67^{d}	3.92 ± 0.67^{abcd}	3.92 ± 1.00^{abcd}
Texture	0	6.50 ± 1.07^{a}	6.40 ± 0.87^{ab}	5.70 ± 1.28^{abcd}	5.80 ± 1.46^{abcd}	6.30 ± 1.28^{abc}	6.30 ± 1.13^{abc}
	2	5.08 ± 1.51^{cd}	4.67 ± 1.50^{d}	5.50 ± 1.17^{abcd}	4.67 ± 1.56^{d}	5.50 ± 1.09^{abcd}	5.17 ± 1.59^{bcd}
	4	5.25 ± 1.48^{abcd}	5.25 ± 1.54^{abcd}	5.08 ± 1.38^{cd}	5.17 ± 1.70^{bcd}	5.08 ± 1.00^{cd}	5.08 ± 1.00^{cd}
Overall preference	0	5.73 ± 1.54^{a}	5.27 ± 1.71^{a}	5.00 ± 1.95^{a}	5.55 ± 1.78^{a}	5.55 ± 1.62^{a}	5.73 ± 1.14^{a}
	2	4.83 ± 1.64^{a}	4.67 ± 1.61^{a}	5.55 ± 1.09^{a}	4.92 ± 1.73^{a}	5.50 ± 1.00^{a}	5.58 ± 1.73^{a}
	4	4.58 ± 1.56^{a}	4.42 ± 1.51^{a}	4.75 ± 1.29^{a}	4.92 ± 2.02^{a}	4.42 ± 1.51^{a}	4.92 ± 1.56^{a}

*Different letters indicate significant difference at the level of $p<0.05$

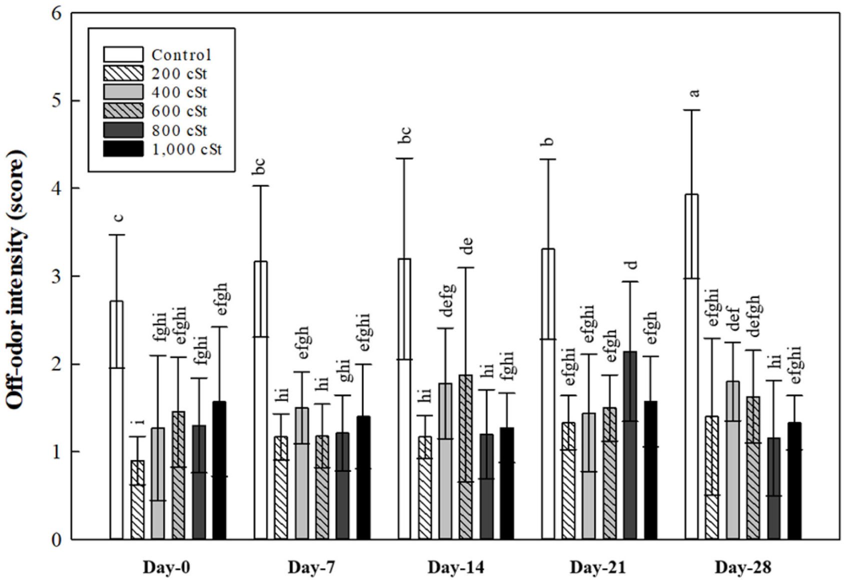

Fig. 4. Deodorizing effects of the one-way gas valve according to storage time and different open pressure level.

or absence of the one-way gas valve; however, the valve effectively reduced the release of Kimchi odor during storage compared to the valve-free control pouch (Fig. 4). The volatile components of Kimchi are one of the most influential factors in sensory characteristics of Kimchi products. The main odor-active volatile components of Kimchi are very diverse and are reportedly produced from precursors that include sulfoxides, thioglucosides, sulfur-containing compounds, and sulfonium compounds in napa cabbage, garlic, onion, ginger, and green onions. The sulfur-containing compounds account for approximately 85% of the odor-active volatile compounds of fermented Kimchi products. Especially, the odor-active volatile components generated during the fermentation of Kimchi products can produce a very strong smell (high flavor dilution value). These include dimethyl disulfide, allyl propyl sulfide, allyl sulfide, methyl propyl disulfide, dipropyl disulfide, and allyl propyl disulfide, which are mainly off-odor components derived from garlic.[11,26-31] These off-odor substances produced by the fermented Kimchi reduce consumer preference for Kimchi products, which is undesirable in the competitive marketplace. Activated carbon can physically deodorize the surrounding atmosphere by collecting and sequestering off-odor components. This deodorizing activity of activated carbon reportedly depends on the type of raw material, pore size (surface area), structure, and particle size.[32,33] The activated carbon used in this study was made from oak as a raw material. Activated carbon seems to have an effective deodorizing function by adsorbing Kimchi off-odor.

Conclusion

The one-way gas valve system developed in this study was designed to prevent the breakage of the package due to excessive CO_2 production and to reduce the leakage of Kimchi odor. The one-way gas valve can prevent breakage of the Kimchi package by controlling CO_2 emission and reduce the leakage of Kimchi odor. In addition, the one-way gas valve did not affect the sensory characteristics of taste, color, and texture, as well as the pH of Kimchi products. The valve-type active package system using a natural deodorant, such as activated carbon, is expected to contribute to a safer product that is desirable to consumers.

Acknowledgements

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