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Container System Actively Maintaining High CO_2 Concentration for Improved Sensory Quality of *Kimchi*

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Abstract A *kimchi* container actively controlling CO_2 concentration by timely flushing of CO_2 gas was structured and tested in its capability and effectiveness because high CO_2 concentration enhances the sensory flavor of the product. The inlet and outlet valves of CO_2 gas were programmed to open and close allowing synchronous vent/CO_2 flush according to the requirements of its dissolution in the contained *kimchi*. During the chilled storage, the headspace of container could be maintained at desired high CO_2 concentration providing the preferred *kimchi* in sensory quality compared to control of the conventional container. However, there was no significant difference between the high CO_2 container and control (container simply closed with air) in *kimchi* quality attributes of pH, titratable acidity, total viable bacterial count, *Lactobacillus* sp. count and *Leuconostoc* sp. count. The flow rate and time interval of CO_2 flushing need to be adjusted considering the *kimchi* amount, headspace volume and ripening time. The designed system has potential to be applied in refrigerator appliances in homes and food service industry.

Keywords Lactic acid fermented food, Active control, Carbon dioxide, Sensory quality, Modified atmosphere

Introduction

Kimchi, a Korean major fermented vegetable, has unique quality characteristics which is dynamic with storage time due to activity of contained live lactic acid bacteria. The quality is also determined by the flavor and CO_2 gas produced by the on-going fermentation. The quality and organoleptic properties of *kimchi* have been reported to benefit from high CO_2 atmospheric conditions[1)]. In Korean household, plastic or metal containers are widely used for storing *kimchi*. During the storage, the containers are opened and closed many times to take out part of the product. Maintaining high CO_2 concentration in the container all through these behavioral procedures is expected to be helpful for sensory preference of *kimchi*. Thus the container design to allow intermittent CO_2 gas supply has a potential to be applied for the household storage of *kimchi* in refrigerator. Nowadays some refrigerators are equipped with small CO_2 gas cylinder to make carbonated water and thus the *kimchi* container system may use it for CO_2 supply to keep the high CO_2 concentration inside.

Therefore, this study aims to develop a *kimchi* container system able to actively modify the container atmosphere and keep high CO_2 concentration beneficial for consumer preference. Way to consistently maintain high CO_2 was implemented stepwise.

Materials and Methods

1. *Kimchi* container system and storage trial

As the first step for developing the *kimchi* container system to keep the internal CO_2 concentration at high level, a structure was conceptualized as shown in Fig. 1. To the headspace of the container, CO_2 gas was designed to flow inward through a gas inlet valve from a small CO_2 cylinder and a gas outlet valve was synchronized with inlet valve in its opening and closing, which helped to flush it at normal atmospheric pressure. The repetitive vent/CO_2 flush operations could be directed or varied by opening/closing actuation of the inlet and outlet valves programmed in the control board. In realizing the concept, 10 L polypropylene container (32 × 25 × 18 cm with a wall thickness of 2 mm) was fabricated with installation of inlet and outlet valves of solenoid type (diameter of 3 mm and length of 4 cm). The inlet valve was connected to CO_2 gas cylinder and outlet was open to the atmosphere. Their opening and closing were synchronized in order to flush the container and avoid the overpressure inside the container.

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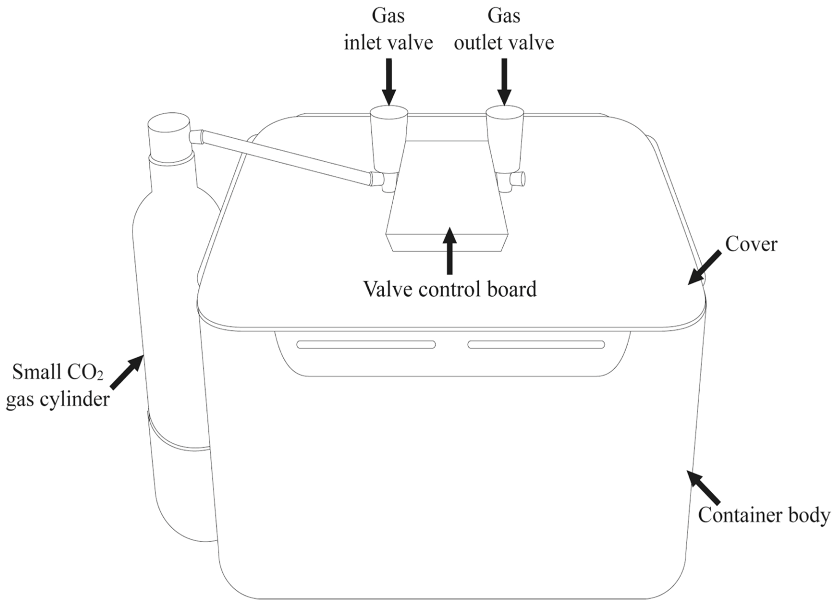

Fig. 1. *Kimchi* container system for keeping the internal CO_2 concentration at high level by vent/CO_2 flush method.

As the first trial to test a vent/CO_2 flush concept preliminarily, 7 kg *kimchi* prepared (with Chinese cabbages of 5 × 5 centimeter) at Ungcheon Agricultural Cooperative (Changwon, Korea) was used for the experiment after immediately transferred to the laboratory. The salt concentration of the product measured by Salt Meter (Model TM-301, Takemura Electric Work Ltd., Tokyo, Japan) was 3.0%. The container was flushed with high CO_2 concentration (higher than 80% at normal atmospheric pressure, i.e., above 0.8 atm in partial pressure) condition initially and then stored at 7°C. In the course of storage, the container was opened to take out 2 kg of *kimchi* sample at two different times following the common consumer behavior in the household and then closed again to be flushed to the condition of high CO_2 concentration (higher than 80% at normal atmospheric pressure or above 0.8 atm in partial pressure). After 14 days of the storage, the container was opened to examine the final quality of *kimchi*. Control container of non-flushed atmosphere was filled initially with 7 kg and subjected to the same storage and sample removal conditions for comparison purpose. Samples taken out each time corresponded to the state of under-ripened (0.2-0.6% of total acidity), optimal-ripened (0.6-0.8 of acidity) and over-ripened (acidity above 0.8%) *kimchi*[2,3]. Container gas concentration in partial pressures of CO_2, O_2 and N_2 was measured by a gas chromatograph (Varian CP3800, Palo Alto, CA, USA) for the gas sample of 1 mL taken from the headspace through silicon sampling port by gas-tight syringe. The gas chromatograph had been equipped with Alltech CTR I Column (Alltech Associates, Inc., Deerfield, IL, USA) and a thermal conductivity detector. The *kimchi* samples taken out from the container were measured in pH, acidity, microbial counts and sensory flavor.

Based on the results from the first trial of simple vent/CO_2 flushing, a patterned CO_2 flushing in pre-set time schedule (time-controlled vent/CO_2 flushing) was devised and applied to the same container filled with 8 kg *kimchi* (salt content: 2.4%). Initial flushing at flow rate of 2.4 L/min was applied for 2.5 minutes and then periodical flushing during the subsequent storage at 5°C was executed for 50 seconds at the same flow rate every 6 hours before reaching the state of optimum ripening. At the state of optimum *kimchi* ripening, the container was opened to take out 3 kg of *kimchi* simulating the consumer behavior and then closed again with the CO_2 flushing same as the initial one. The flushing was applied for 5 minutes considering the increased headspace. The flushing time interval was changed to 12 hours after the state of optimum ripening because slighter CO_2 flow was enough to maintain the high CO_2 concentration in the container due to high amount of CO_2 already dissolved in the contained *kimchi*. Control container of normal air without CO_2 flushing was given to the same storage and procedure of its opening and *kimchi* removal. During the storage, container's CO_2 gas concentration was measured by a gas analyzer (Checkmate 3, PBI Dansensor, Ringsted, Denmark). *Kimchi* taken out from the container was submitted to the measurement of quality attributes.

2. Measurement of *kimchi* quality attributes

Quality attributes of pH, titratable acidity and microbial counts of total viable bacteria, *Lactobacillus* and *Leuconostoc* species were measured for *kimchi* liquid taken also from the product in the container. The pH of the *kimchi* brine was measured by an Orion Model 920A pH Meter (Orion Research Inc., Boston, USA). The acidity was determined in lactic acid concentration by titrating 5 g of *kimchi* brine sample with 0.1 N NaOH until pH 8.1 of end point was attained. Counting procedures for total viable organisms, *Lactobacillus* and *Leuconostoc* species were carried out for the liquid sample diluted with 0.05% (w/v) peptone water in accordance with the method of Lee and Paik[4]. Total viable bacteria were enumerated using plate counting agar (PCA; Becton, Dickinson and Company, Sparks, NV, USA) plates incubated for 3 days at 30°C. *Lactobacillus* and *Leuconostoc* species were enumerated on Lactobacilli MRS agar (Becton, Dickinson and Company, Sparks, NV, USA) supplemented with 0.002% bromophenol blue by incubating for 3 days at 25°C. The distinct color discernible in the colony (white or bright blue color for *Lactobacillus* and dark blue color for *Leuconostoc*) on the agar plate was assisted in the counting of the species. The microbial count was expressed in colony forming unit (CFU) per mL of *kimchi* solution. All the data are the averages of three samples at least. In a separate experiment, hedonic flavor score was assessed for the *kimchi* samples by 6 or 7 panel members. Score scale allocated was from 1 to 5 for the first trial while the scale from 1 of 'extremely displeasant' to 7 of 'extremely pleasant' was used in the second trial. Statistical significance of difference between the treatments was evaluated by t-test function in Microsoft Excel®.

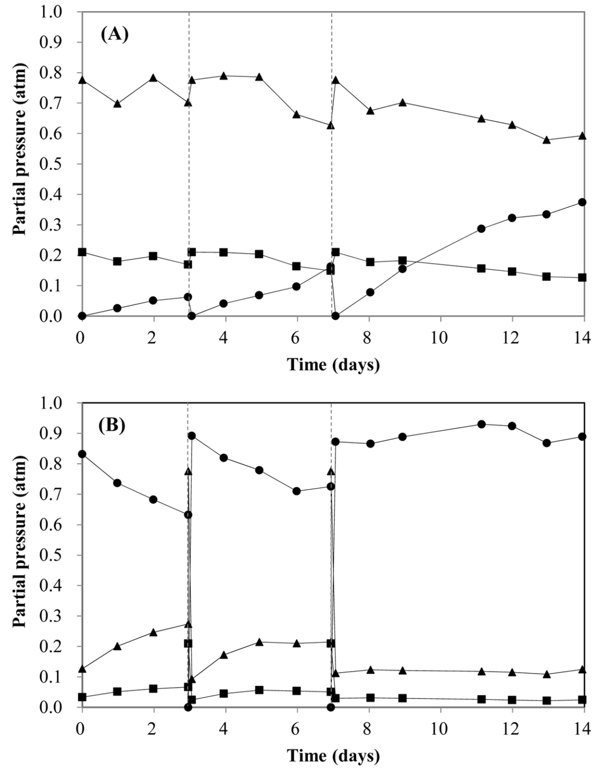

Fig. 2. Atmosphere profile in 10 L control container (A) or vent/CO_2 flush container (B) containing 7 kg *kimchi* at 7°C. Vertical dotted bars represent the time of *kimchi* take-out. ●, CO_2; ■, O_2; ▲, N_2.

Results and Discussion

1. Container system with simple vent/CO_2 flushing

When CO_2 gas was flushed into the container up to high CO_2 concentration initially or after the time of opening the container (above 0.83 atm), the CO_2 concentration decreased continuously during the subsequent storage in Fig. 2B. The rate and magnitude of CO_2 concentration decrease were higher at earlier storage time (down to 0.63 atm at 3.0 day, 0.73 atm at 6.0 day and 0.89 atm at 13.9 day) probably because there was higher amount of *kimchi* un-ripened in the container during initial storage. High solubility of CO_2 in aqueous or fatty foods is well known and works for beneficial effect sometimes[5,6]. Thus the flushed CO_2 gas would have been dissolved into aqueous part of *kimchi*. In the last part of storage (after 6.9 day with *kimchi* acidity of 0.64% according to Table 1), the decrease of headspace CO_2 concentration with time was negligible, which indicated that no further CO_2 dissolution into *kimchi* did occur. Even with the decrease of CO_2 concentration, the flushed container maintained CO_2 partial pressure above 0.63 atm through the whole storage time. On the other hand, the CO_2 concentration in control container increased slowly and persistently with time; the rate and degree of increase were higher in the later storage part (up to 0.06 atm at 3.0 day, 0.16 atm at 6.9 day and 0.37 atm at 13.9 day) (Fig. 2A). The higher CO_2 concentration in the control container at the later storage period (3 kg remaining after taking out the *kimchi* twice) compared to initial part was presumed to be caused by the combination of fermentation activity and CO_2 release from the fully fermented *kimchi* with high dissolved CO_2, which would have been determined by equilibration relation[7].

Container with the simple vent/CO_2 flush mechanism experiencing high CO_2 concentration resulted in significantly better sensory flavor after optimal ripening (6.9 days of acidity 0.64% and 13.9 days of acidity 1.19%), but not in the un-ripened state (3.0 days of acidity 0.32%), compared to control treatment (Fig. 3). Beneficial effect of high CO_2 packaging on sensory flavor of optimally ripened *kimchi* was reported elsewhere[1]. High CO_2 partial pressure or concentration would have resulted in high content of the dissolved CO_2 in the product and thus better fresh cool taste. High dissolved CO_2 in the food product has been reported to give sparking taste[8,9]. However, the different container atmosphere observed in Fig. 2 did not affect the chemical and microbial quality of *kimchi* prod-

Table 1. Change of the ripening attributes of *kimchi* (salt 3.0%) stored in the container system at 7°C

Container*	Attribute	Time (days)			
		0	3.0	6.9	13.9
Control	pH	5.27 ± 0.03	5.59 ± 0.00	4.41 ± 0.02	4.00 ± 0.07
	Acidity (%)	0.46 ± 0.00	0.32 ± 0.00	0.64 ± 0.01	1.19 ± 0.00
	Microflora (log(CFU/mL))				
	Total viable bacteria	6.28 ± 0.14	6.95 ± 0.06	9.18 ± 0.04	9.74 ± 0.05
	Lactobacillus sp.	5.42 ± 0.27	6.28 ± 0.11	8.15 ± 0.14	9.86 ± 0.08
	Leuconostoc sp.	6.03 ± 0.14	7.15 ± 0.10	9.25 ± 0.00	8.36 ± 0.32
Vent/CO_2 flush	pH	5.27 ± 0.03	5.62 ± 0.01	4.44 ± 0.02	4.06 ± 0.01
	Acidity (%)	0.46 ± 0.00	0.31 ± 0.01	0.71 ± 0.01	1.19 ± 0.00
	Microflora (log(CFU/mL))				
	Total viable bacteria	6.28 ± 0.14	7.02 ± 0.13	9.18 ± 0.03	9.74 ± 0.29
	Lactobacillus sp.	5.42 ± 0.27	6.55 ± 0.17	8.14 ± 0.06	9.97 ± 0.05
	Leuconostoc sp.	6.03 ± 0.14	7.14 ± 0.18	9.23 ± 0.08	8.40 ± 0.17

*For the container atmosphere, refer to Fig. 2.

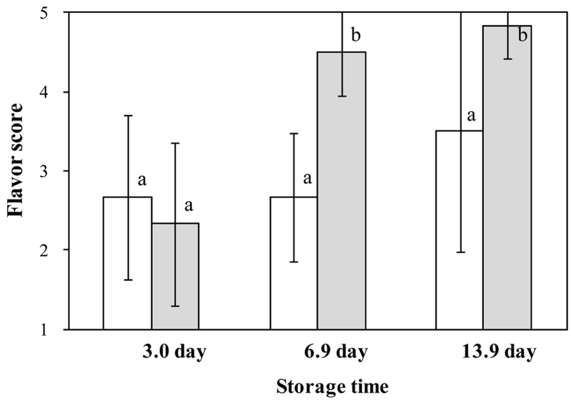

Fig. 3. Sensory flavor score of *kimchi* compared between treatments given in Fig. 2 at different ripening stages (n=6). □: control, ■: vent/CO_2 flush container. Scale range is from 1 to 5. The different letters for the bars of the flavor scores indicate significant differences between the treatments ($p \le 0.05$).

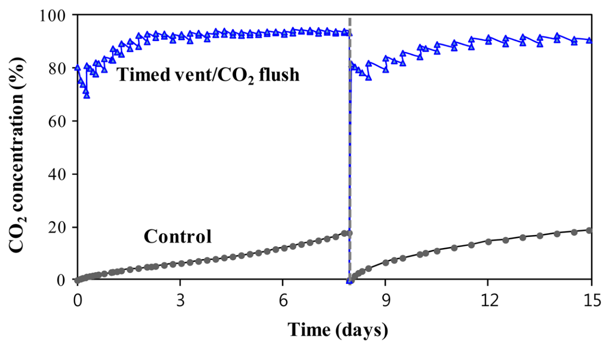

Fig. 4. Profiles of CO_2 concentrations in the *kimchi* container (10 L) which was in time-controlled vent/CO_2 flush mode or just closed hermetically (control) at 5°C. Dotted vertical line shows the time of opening the container to take out 37.5% of *kimchi* in the container (3 kg from total 8 kg).

uct significantly (Table 1). While some researchers reported that modified atmosphere of high CO_2/low O_2 contributed to good survival of probiotic bacteria[10, 11], noticeable difference in the lactic acid bacteria counts was not found in this work. Maintaining high CO_2 concentration in the container was found to be beneficial for human preference of *kimchi* without affecting the ripening rate.

2. Container system with time-controlled vent/CO_2 flushing

As a way to actively and dynamically modify the *kimchi* container atmosphere, continuous and intermittent flushing was devised as a time-controlled mode, whose CO_2 concentration profile measured by gas sensor was compared with that of control in Fig. 4. CO_2 flushing synchronized with outlet venting in time-controlled manner was effective to maintain the high CO_2 concentration persistently in the container. After initial attainment of high CO_2 concentration above 0.8 atm (80%) by 2.5 minute flushing, it decreased to 70% rapidly in first 6 hours and increased again to 81% by 50 second CO_2 flushing. The patterned decrease and increase of CO_2 concentration were repeated with its general trend of movement toward higher range at smaller fluctuation. After 2.3 days the fluctuation became very little for the concentration to stay at 93%. This fluctuated shift toward the high CO_2 concentration also happened after opening and closing the container at 7.9 days. The control *kimchi* container experienced steadily increased CO_2 concentration with storage time after container

Table 2. Change of the ripening attributes of *kimchi* (salt 2.4%) stored in the container system at 5°C

Container*	Attribute	Time (days)		
		0	7.9	14.9
Control	pH	5.26 ± 0.03	4.24 ± 0.01	4.12 ± 0.02
	Acidity (%)	0.38 ± 0.00	0.65 ± 0.00	0.88 ± 0.00
	Microflora (log(CFU/mL))			
	Lactobacillus sp.	6.38 ± 0.11	8.74 ± 0.04	9.27 ± 0.03
	Leuconostoc sp.	6.49 ± 0.08	9.23 ± 0.03	8.56 ± 0.07
Vent/CO_2 flush	pH	5.26 ± 0.03	4.25 ± 0.01	4.13 ± 0.04
	Acidity (%)	0.38 ± 0.00	0.65 ± 0.00	0.89 ± 0.01
	Microflora (log(CFU/mL))			
	Lactobacillus sp.	6.38 ± 0.11	8.74 ± 0.07	9.23 ± 0.01
	Leuconostoc sp.	6.49 ± 0.08	9.26 ± 0.01	8.54 ± 0.06

*For the container atmosphere, refer to Fig. 4.

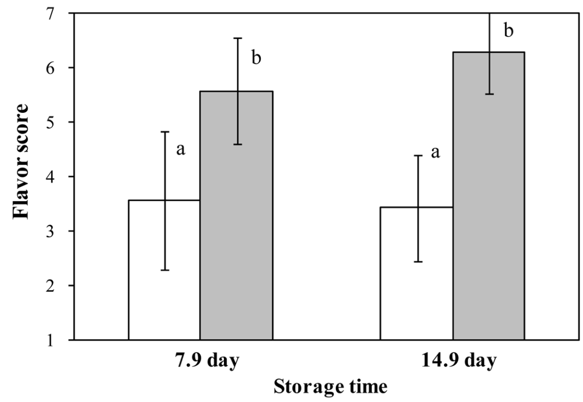

Fig. 5. Sensory flavor score of *kimchi* compared between treatments given in Fig. 4 at different ripening stages (n=7). □: control, ■: vent/CO_2 flush. Scale range is from 1 to 7. The different letters for the bars of the flavor scores indicate significant differences between the treatments ($p \leq 0.05$).

closing (up to 18 and 19% at 7.9 and 14.9 days, respectively). The time-controlled vent/CO_2 flush container having maintained high level CO_2 concentration provided better sensory flavor score than the control both at 7.9 days and at 14.9 days, when *kimchi* passed the ripened state of acidity 0.6% (Fig. 5 and Table 2). However, there was no difference in chemical and microbial qualities between treatments (Table 2).

Conclusions

The *kimchi* storage container system able to actively modify its atmosphere and keep internal high CO_2 concentration was developed with implementation of a programmed vent/CO_2 flushing. The time-controlled vent/CO_2 flushing mode could maintain the desired high level of CO_2 concentration inside the container through the storage and improved the consumer's preference of *kimchi* product. The developed container system has potential to be applied to commercial *kimchi* refrigerators widely used in Korean households.

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