KOREAN JOURNAL OF PACKAGING SCIENCE & TECHNOLOGY
Vol. 26, No. 2 53~60 (2020)
https://doi.org/10.20909/kopast.2020.26.2.53

# Fresh Produce Container Operated with a Routine of Hypobaric Application, $CO_2$ Injection and Diffusion Tube Opening for Keeping Beneficial Modified Atmosphere

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**Abstract** A concept of household container to create and keep the modified atmosphere (MA) beneficial for fresh produce mix was devised and tested under typical chilled storage conditions of 3°C. The container system containing mixed products is initialized by applying weak hypobaric condition (0.9 atm) and subsequently injecting $CO_2$ gas at an appropriate low level (0.03 atm). The passive atmosphere modification by produce respiration is then induced to reach a target until gas diffusion tube of proper dimension starts to open. The design was made to attain quasi-steady state mass balance of $O_2$, $CO_2$ and $N_2$ to maintain the desired MA through the storage. Interrupted opening for taking out or placing some products was to reinitialize the loop of control logic. The developed concept was tested by the container which held commodities of spinach, pak choi, oyster mushroom, peeled onion, strawberry and cut carrot. The target optimum MA of 11% $O_2$ and 10% $CO_2$ (0.11 and 0.10 atm, respectively) was set to avoid injurious range of $O_2$ and $CO_2$ concentrations for any commodities. The developed container system could work to reach and maintain beneficial MA of 0.10-0.12 atm $O_2$ and 0.07-0.10 atm $CO_2$ close to the target during the storage contributing to quality retention of products measured in weight loss, chlorophyll content of spinach, ascorbic acid content of pak choi, color of onion, texture of oyster mushroom, bacterial count of strawberry and carotenoids of carrot. The container system shows potential to improve current preservation practice of fresh produce mix on consumers' level.

**Keywords** Produce container, Modified atmosphere, Hypobaric application, Carbon dioxide injection, Gas diffusion tube

## Introduction

With increase in the consumers' demand for fresh vegetables and fruits due to their health benefits, there has been a growing interest in their preservation technology. In aspects of produce supply and consumption, handling and storage in households emerge to be important to keep freshness and reduce food losses[1,2]. Modified atmosphere (MA) packaging under chilled temperature in consumer level is helpful to preserve the produce quality up to the point of consumption. Refrigerators are widely accepted in food supply chain and there have been attempts to create and maintain desired MA in small containers adoptable in transportation and households[3-6]. The applied technologies include increased tightness, use of diffusion channel, sophisticated valve system, active gas flushing, etc. Applying MA in household refrigerators can maximize its preservative effectiveness through constantly maintained low temperature and availability of electricity can also make it possible to apply more active control measures. On the other hand, challenges or limitations would come from the variability of consumer behavior in product stock management and rotation. Often mixes of several commodities are stored together in the container and some of them are placed or taken out intermittently, which raises the problem of setting target MA range not based on single commodity. The chances and challenges need to be tackled and harmonized with application of scientific principle and available engineering devise to realize the MA in the household refrigerators.

In principle, MA in packages or containers containing fresh produce is influenced by the respiration activity of consuming oxygen and producing carbon dioxide. Any control measures, whether simple or sophisticated, should have balance between produce respiration and container gas exchange. Several possible tools were examined in this study for creating and keeping the desired MA in container to be placed in household refrigerators. Even though any innovative tools may be considered, it is better to apply or modify currently available technologies in terms of cost effectiveness and practical usefulness.

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Because plastic container does not usually provide the necessary degree of gas exchange, gas transfer devices such as diffusion tube and perforation are thought to be useful at relative easiness and affordable cost[3]. Slight vacuumizing may be supplied in home appliance taking into consideration that small household containers to store foods under partial vacuum have been available in market[7]. Initial application of sub-atmospheric conditions will reduce initial oxygen concentration and can contribute to fast achievement of desired reduced oxygen concentration in the container[8]. Exposure of fresh produce even for short time is known to enhance natural defense mechanism against disease by removal of detrimental volatile metabolic products[9]. It is noted that canister or cylinder of carbon dioxide has been introduced recently in the home appliance to prepare carbonated water on site. Some degree of carbon dioxide injection may be applied to the MA container to attain quick achievement of required carbon dioxide level[5]. Even though gas sensors may be employed to operate the system in articulate way, price and durability excluded their use in this study.

Thus, this study constructed a container system equipped with gas diffusion tube, small vacuum pump and $CO_2$ cylinder to keep the desired MA for fresh produce mix through the extended storage. Control routine consisting of triggered vacuuming, $CO_2$ injection and subsequent opening of the gas diffusion tube has been developed to keep the optimal MA as long as possible under possible consumer behavior. The container system with devised routine was tested for a typical fresh produce mix under typical scenario of consumer use condition.

## Materials and Methods

### 1. MA container system

An innovative MA container system was developed in the concept and fabricated like Fig. 1 to keep fresh produce in the refrigerator at home. It consists of a rigid plastic box connected with a small vacuum pump and a carbon dioxide cylinder. There is attached a gas diffusion tube to be opened and closed by an on-off valve. The operational concept is to initially apply a weak vacuum to lower the $O_2$ concentration, and then inject the appropriate amount of $CO_2$ to attain normal atmosphere, which is expected to help quickly reach the desired MA by produce respiration activity under the closed state of the container. And when the $O_2$ concentration is reduced down to a tolerance level or the $CO_2$ concentration increases up to a tolerance limit in the subsequent storage, the gas diffusion tube attached onto the container is to open for enhancing the gas exchange for keeping the desired MA.

To fulfil the developed concept in practice, a polypropylene container (wall thickness of about 2 mm) in about 10 L size (dimension: 32 × 23 × 18 cm) to be placed inside home refrigerator was attached with a diffusion tube (1.0 cm in diameter and 5.0 cm in length). A 605-mL $CO_2$ cylinder (Delight Co. Paju, Korea) and a small portable vacuum pump (WP55, Conair Co., East Windsor, New Jersey, USA) fastened on outside wall of refrigerator were connected to the 3-way valve leading to the quick-connect valve on the container cover through Tygon® tubing (inlet diameter 1/8 inch) and a fitting (SS-QC4-D-400, Swagelok Co.). A solenoid $CO_2$ regulator ($CO_2$ Supermarket, South Milford, UK) was placed onto the $CO_2$ cylinder to keep the inlet pressure at 2 bar. The operation of the vacuum pump and $CO_2$ gas supply was programmed on the control board and executed semi-automatically.

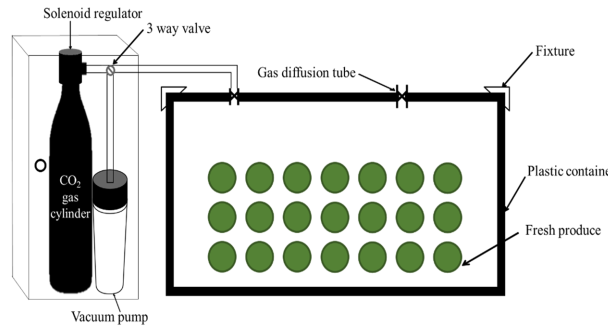


**Fig. 1.** MA container system with functions of initial vacuumizing, $CO_2$ injection and subsequent diffusive gas flow.

### 2. Control routine of the MA container system

Automatic control routine was devised to keep the container atmosphere close to the optimal MA as long as possible without causing any physiological injury to the produce due to low oxygen and high carbon dioxide concentrations. Target MA was assumed to be set up depending on the commodities to be loaded in the container. Even though one single commodity may be placed in the container, usual practices in households are to store several products in the container. It may be deduced that any commodities should not be exposed to oxygen concentration lower than their lower tolerance limits and carbon dioxide concentration higher than their upper tolerance limits. This reasoning states that the containers' oxygen concentration ($[O_2]$) should stay above the highest of the lower oxygen tolerance limits and the carbon dioxide concentration ($[CO_2]$) should be maintained below the lowest of the upper carbon dioxide tolerance limits of commodities. This study set up a rule applied to a typical produce mix consisting of spinach, pak choi, oyster mushroom, onion, strawberry and carrot. Thus, the recommended MAs of spinach ($O_2$ 7-10%, $CO_2$ 5-10%), pak choi ($O_2$ 0.5-2%, $CO_2$ 2-10%), oyster mushroom ($O_2$ 2-5%, $CO_2$ 10-15%), onion ($O_2$ 1-21%, $CO_2$ 0-15%), strawberry ($O_2$ 4-10%, $CO_2$ 15-20%) and carrot ($O_2$ 1-21%, $CO_2$ 0-15%) were considered as shown in Fig. 2 [10, 11] to present the lower $[O_2]$ limit of 7% and the upper $[CO_2]$ limit of

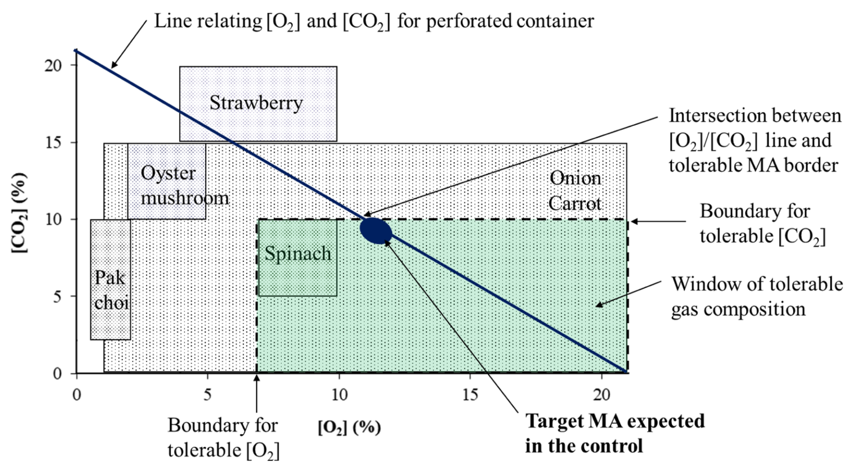


**Fig. 2.** Derivation of target MA for container containing several commodities. Rectangular boxes of dotted image depict optimal MA for the commodities[20,21]. The shaded area shows target MA consisting of tolerable $O_2$ and $CO_2$ concentrations for all the commodities. Black spot is the expected optimum MA in the real control. See the text for details in derivation.

10% of shaded area. That is, the lower $[O_2]$ limit of 7% is defined as the highest of 7, 0.5, 2, 1, 4 and 1% for all the commodities and the upper $[CO_2]$ limit of 10% is the lowest of 10, 10, 15, 15, 20 and 15%. For the fresh produce MA container attached with gas diffusion tube or perforation, relationship of $[O_2]$ and $[CO_2]$ applies to be $[CO_2]$=21-$[O_2]$ at equilibration [12,13]. Because fresh produce is preserved better with reduced oxygen and elevated carbon dioxide concentrations inside the tolerance boundary, the desired optimum would be located onto the interaction between the $[O_2]$/$[CO_2]$ equilibration line and inside the tolerance window. For the commodity mix of Fig. 2, the target MA will be dark spot of $[CO_2]$ of 10% (0.10 atm) with $[O_2]$ of around 11% (0.11 atm) for the best quality preservation.

Now considering the conditions where the commodities are placed in the container, the mathematical model was applied to examine possibility of keeping the target atmosphere in the container. Container atmosphere is estimated using mathematical modelling which utilizes solution of differential equations based on the mass balance of oxygen, carbon dioxide and nitrogen in the fresh produce container with gas diffusion tube[14]:

$$\frac{dn_{O2}}{dt} = \frac{ND_{O2}A(0.21p_a - p_{O2})}{L_d}\left(\frac{1}{RT}\right) + \frac{\bar{P}_{O2}S(0.21p_a - p_{O2})}{B} - \sum W_i R_{O2,\,i} \tag{1}$$

$$\frac{dn_{CO2}}{dt} = \frac{ND_{CO2}A(0.00 - p_{CO2})}{L_d}\left(\frac{1}{RT}\right) + \frac{\bar{P}_{CO2}S(0.00 - p_{CO2})}{B} + \sum W_i R_{CO2,\,i} \tag{2}$$

$$\frac{dn_{N2}}{dt} = \frac{ND_{N2}A(0.78p_a - p_{N2})}{L_d}\left(\frac{1}{RT}\right) + \frac{\bar{P}_{N2}S(0.78p_a - p_{N2})}{B} \tag{3}$$

where $n_{O2}$, $n_{CO2}$ and $n_{N2}$ are respective mole numbers in the container at time $t$ (h), respectively; $p_{O2}$, $p_{CO2}$ and $p_{N2}$ are respective partial pressure of $O_2$, $CO_2$ and $N_2$ gas in the container at time $t$; $D_{O2}$, $D_{CO2}$ and $D_{N2}$ are the gas diffusivities for $O_2$, $CO_2$ and $N_2$ gas in air, respectively (0.0622, 0.0493 and 0.0627 $m^2\ h^{-1}$); $N$ represents the state of the diffusion tube ($N$ =1 when the tube is open; $N$=0 when the tube is in close state); $A$ is cross-sectional area of diffusion tube ($m^2$); $L_d$ is distance of gas diffusion through the gas diffusion tube corrected as sum of its length and 1.1 × diameter (m); $B$ is the wall thickness of the plastic container (mm); $S$ is the surface area of the plastic container ($m^2$); $\bar{P}_{O2}$, $\bar{P}_{CO2}$ and $\bar{P}_{N2}$ are the respective gas permeabilities of the polypropylene layer against $O_2$, $CO_2$ and $N_2$, respectively ($3.52 \times 10^{-5}$, $1.02 \times 10^{-4}$ and $7.02 \times 10^{-6}$ mol mm $m^{-2}$ $atm^{-1}$ $h^{-1}$); $R$ is the gas constant ($8.205 \times 10^{-5}$ atm $m^3$ $K^{-1}$ $mol^{-1}$); $T$ is temperature (K); $W_i$ is the produce weight of commodity $i$ (kg); $R_{O2,i}$ is the $O_2$ consumption respiration rate of commodity $i$ (mol $kg^{-1}$ $h^{-1}$); $R_{CO2,i}$ is the $CO_2$ production respiration rate of commodity $i$ (mol $kg^{-1}$ $h^{-1}$); and $p_a$ is normal atmospheric pressure (1 atm).

The respiration rates of the products in Eqs. (1) and (2) are supplied as a function of $O_2$ and $CO_2$ concentrations[15]:

$$R_{O2,\,i} \text{ or } R_{CO2,\,i} = \frac{V_{m,\,i}p_{O2}}{K_{m,\,i} + (1 + p_{CO2}/K_{i,\,i})p_{O2}} \tag{4}$$

where $V_{m,i}$, $K_{m,i}$ and $K_{i,i}$ are respiration model parameters of commodity $i$. The respiration parameters at 3°C were retrieved

**Table 1.** Respiration model parameters of Eq. (4) at storage temperature of 3°C

| Commodity | Respiration expression | $V_m$ (mol kg$^{-1}$ h$^{-1}$) | $K_m$ (atm) | $K_i$ (atm) | Source |
|---|---|---|---|---|---|
| Spinach | $R_{O2}$ | $7.79 \times 10^{-4}$ | 0.035 | 0.221 | Jo *et al.*[13]), Postharvest Center[22]) |
| | $R_{CO2}$ | $6.18 \times 10^{-4}$ | 0.033 | 0.170 | |
| Pak choi | $R_{O2}$ | $1.13 \times 10^{-4}$ | 0.000 | 1.000 | This study |
| | $R_{CO2}$ | $8.52 \times 10^{-5}$ | 0.000 | 1.000 | |
| Oyster mushroom | $R_{O2}$ | $2.94 \times 10^{-3}$ | 0.058 | 1.388 | An & Lee[23]) |
| | $R_{CO2}$ | $1.68 \times 10^{-3}$ | 0.000 | 0.839 | |
| Onion | $R_{O2}$ | $1.48 \times 10^{-4}$ | 0.014 | 0.179 | This study |
| | $R_{CO2}$ | $8.95 \times 10^{-5}$ | 0.058 | 0.122 | |
| Strawberry | $R_{O2}$ | $2.95 \times 10^{-4}$ | 0.035 | 1.197 | An *et al.*[24]) |
| | $R_{CO2}$ | $1.54 \times 10^{-4}$ | 0.000 | 1.456 | |
| Carrot | $R_{O2}$ | $5.66 \times 10^{-4}$ | 0.012 | 0.033 | An & Lee[23]) |
| | $R_{CO2}$ | $3.09 \times 10^{-4}$ | 0.008 | 0.083 | |

from relevant literatures or determined in this study (Table 1). The solution of Eqs. (1)-(3) given initially in moles of $O_2$, $CO_2$ and $N_2$ gases can be converted into their respective partial pressures by using Ideal Gas Law through the storage time.

When the container is loaded with the products, vacuumized slightly (to about 0.9 atm) and injected with carbon dioxide (to about 0.03 atm) to recover the normal atmospheric pressure, the initial condition of oxygen, carbon dioxide and nitrogen concentrations ($p_{O2}$, $p_{CO2}$ and $p_{N2}$) is supplied to the solution of Eqs. (1)-(3). At the closing of container, solution of Eqs. (1)-(3) with $N$=0 can estimate the gas compositional change and determine the time for the container atmosphere to reach the lower limit of [$O_2$] (11% in this case of produce mix, $p_{O2}$ of 0.11 atm) or the upper limit of [$CO_2$] (10% for the produce mix, $p_{CO2}$ of 0.10 atm). At this time, the gas diffusion tube should be opened to increase the gas exchange in order to avoid physiological injury due to too low oxygen or too high carbon dioxide concentration. The gas diffusion tube of proper size needs to be selected for creating stable and desired level of container atmosphere from preliminary simulation of the container atmosphere. When there may occur occasions to require container opening for a variety of purposes such as changing the components in the container during the course of storage, the initialization of vacuumizing and carbon dioxide injection under closed state of gas diffusion tube will be applied on reclosing of the container. If some products are taken out from or added to the container, the products included may be changed in their presence and weights to be taken into account in the simulation for finding new time of tube opening for another cycle of storage. Then storage would continue as long as any products are in the container.

## 3. Commodity storage test using an MA container

The concept of fresh produce MA container equipped with the control routine was tested by a storage test at 3°C, a commonly adopted temperature of the domestic refrigerator. An MA container equipped with a diffusion tube, vacuumizing/$CO_2$ flushing device and control mechanism, as stated above, was constructed and used for the storage experiment of a mix of spinach, pak choi, oyster mushroom, peeled onion, strawberry and cut carrot. The commodities were selected from preliminary survey on several home refrigerators.

Commodities for the storage test at 3°C were purchased in a local market in Changwon, South Korea and stored following usual preparation practices of consumers. 100 g of spinach and 100 g of pak choi were placed in 11 μm thick high density polyethylene (HDPE) open bag of 25 × 35 cm size individually. 200 g of oyster mushroom were placed in 16 × 12.5 × 6.5 cm size semi-rigid polypropylene (PP) container with macro-holes. 500 g of onion in a peeled state were put into an open HDPE film bag of 30 × 45 cm size. 500 g of strawberries were placed in 18 × 13 × 7 cm size semi-rigid PP container (wall thickness of 0.24 mm on average) with macro-holes. 200 g of carrot were cut to 5 cm and then were placed in HDPE open bag of 25 × 35 cm. And then, the commodities of spinach, pak choi, oyster mushroom, onion and strawberry were placed in the developed MA container. Then the control routine was applied in sequences to the container system after closing the container: vaccumizing, $CO_2$ injection, initiated storage, diffusion tube opening and continued storage. During the storage, the gas diffusion tube initially closed was opened around the time when the container atmosphere reached the lower [$O_2$] limit of 0.11 atm or the upper [$CO_2$] limit of 0.10 atm. After 8 days of storage, the container was opened to take out the spinach and pak choi samples and then loaded with the carrot simulating a kind of consumer behavior, and then was subjected again to the same control routine after reclosing. Again, the gas diffusion tube reclosed would be opened when the container arrived either one of the lower [$O_2$] limit of 0.11 atm and the upper [$CO_2$] limit of 0.10 atm. Storage was ended at 16 days.

For the purpose of control packages, the same HDPE film open packages with normal atmospheric gas composition were prepared for spinach, pak choi, onion and carrot, and the same PP trays were for oyster mushroom and strawberry under air at 3°C.

Container gas composition was measured by taking 1 mL of gas sample from the container through a silicon sampling port attached on the cover. The gas sample was injected into a gas chromatograph (Varian CP3800, Palo Alto, CA, USA) equipped with a thermal conductivity detector and an Alltech CTR I column (Alltech Associates Inc., Deerfield, IL, USA). Gas concentrations of $O_2$ and $CO_2$ were expressed as their partial pressures. The weight loss, chlorophyll content of spinach, ascorbic acid content of pak choi, firmness of oyster mushroom, color of onion, aerobic bacteria count of strawberry and carotenoids content of carrot were measured as quality attributes showing the preservation effectiveness of the container system. Weight loss was determined during the storage by monitoring the weight of the contents of the package before and after storage. Weight loss was expressed as the percentage of the loss of weight with respect to the initial weight. Chlorophyll content of the spinach was determined by measuring the optical density of its extract in 80% acetone at 663 nm and 645 nm by a spectrophotometer[16]. Ascorbic acid content of pak choi was measured according to the AOAC method[17]. The textural attribute of the firmness of the oyster mushroom stipe was measured at a puncturing speed of 120 min/min using a 5 mm diameter round probe using a Rheometer Compac-100 (Sun Scientific Co., Tokyo, Japan). Color of onion was evaluated using a color difference meter (Model JC 801; Color Techno System Corporation, Tokyo, Japan), calibrated using reference plate. The measurements were made directly on the vegetable surface. To determine the total aerobic bacterial counts in colony forming unit (CFU) per gram of the strawberry, 30 g sample was aseptically transferred to a stomacher bag and blended with 90 mL of 0.05% peptone water in a stomacher (Stomacher 400 Circulator, Seward Ltd., UK) at 200 rpm for 1 minute. The solution was serially diluted with 0.05% peptone water, and 1.0 mL of the diluted solution was pour-plated onto Plate Count Agar (Becton Dickinson and Company, Sparks, NV, USA), which was incubated for 48 hours at 30°C. The carotenoids content of carrot was measured by extracting 3 g of sample with 120 mL of 80% acetone according to the method of Cho *et al.*[18]. The concentration of total carotenoids was calculated from the absorbance at 450 nm using the extinction coefficient $E_{1\%} = 2500$. All measurements were presented as average values of the three samples previously placed separately. The statistical significance of the quality difference between treatments was evaluated by t-test.

## Results and Discussion

The simulation model of Eqs. (1)-(3) was employed for predicting the container gas composition at 3°C, which was then used to determine the opening time of gas diffusion tube. The estimated gas composition was in pretty good agreement with experimental $O_2$ and $CO_2$ concentrations during the storage (Fig. 3). The initial vacuum pump operation initiated the container $O_2$ concentration at 0.182 atm (18.2%), which was a little lower than the expected one (0.189 atm) at 10% vacuuming (0.90 atm). The initial $CO_2$ concentration attained by $CO_2$ injection was 0.027 atm (2.7%) a little lower than the targeted one (0.030 atm). The operational variation in the timings of the vacuum pump and the injection valve caused these deviations, which are thought to be in tolerable range not causing serious error in attaining the desired MA. After that, there has been a linear decrease in $O_2$ concentration and an increase in $CO_2$ concentration in the closed state of container until 2.8 days, when the $O_2$ concentration reached the limit of 0.11 atm (11%). The opening time of gas diffusion tube was almost identical with that expected from the simulation (dotted vertical line on left vs. time at slight jumping of $O_2$ and $CO_2$ concentrations in Fig. 3). Because the gas permeation through the container wall of 2 mm thick PP is very low compared to respiration activity consuming oxygen and producing carbon dioxide, the latter dominated to reduce $O_2$ concentration and increase $CO_2$ concentration linearly with time. When the diffusion tube of 1.0 cm diameter and 5.0 cm length was opened, the rate of gas concentration change became much slower to

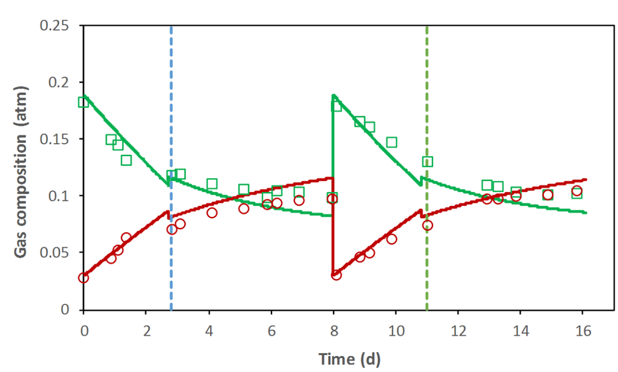


**Fig. 3.** Atmosphere history of fresh produce MA container controlled with initial hypobaric treatment and $CO_2$ infusion at 3°C. □: $p_{O2}$, ○: $p_{CO2}$, solid lines: predicted gas concentrations. The 10 L container equipped with a gas diffusion tube (diameter 1.0 cm and length 5.0 cm) loaded initially with 100 g of spinach, 100 g of pak choi, 200 g of oyster mushroom, 500 g of onion and 500 g of strawberry, and opened to remove the pak choi and spinach and then filled with 200 g of cut (5 cm size) carrot before start of another round of further 8 day storage. Vertical dotted lines indicate actual time of the tube opening.

keep $O_2$ concentration in range of 0.10-0.12 atm (10-12%) and $CO_2$ concentration in 0.07-0.10 atm (7-10%) until day 8 of container opening. Gas diffusion through the tube would have provided significant exchange of $O_2$, $CO_2$ and $N_2$ resulting in quasi-steady state of container atmosphere beneficial for the products. The simulation showed a little lower $O_2$ concentration and a little higher $CO_2$ concentration compared to the respective experimental values. Slight jumps of $O_2$ and $CO_2$ concentrations estimated at 2.8 days of opening the tube is due to the prompt return to normal atmosphere invoking slight inflow of air.

After 8 days of storage, spinach and pak choi were removed and carrot was filled as replacement. After another cycle of hypobaric treatment and the $CO_2$ injection, $O_2$ and $CO_2$ concentrations were created at the same level as the former initial state and then followed again by the $O_2$ concentration decrease and the $CO_2$ concentration increase in similar rates to the former cycle until the former reached the target of 0.11 atm (11%) to make the diffusion tube open at 11 days. The estimated time to reach gas diffusion tube opening was the same of 2.8 days (10.8 days starting from initial storage) even though there has been some change of products with opening the container at 8 days. The $O_2$ concentration was maintained around 0.10 atm (10%) and the $CO_2$ concentration was also located at 0.10 atm (10%) after opening of the diffusion tube until end of storage. And the predicted gas composition after the second opening of the diffusion tube showed sight deviation from experimental $O_2$ and $CO_2$ concentrations as in the former cycle: a little lower $O_2$ and higher $CO_2$ concentrations estimated. Under the limited storage time span, the container was able to keep the atmosphere in the boundary of beneficial MA window. In case that higher $O_2$ and/or lower $CO_2$ concentrations are desired, diffusion tube of shorter length and bigger diameter may be employed experimentally and be determined in its dimension by help of mathematical simulation[19].

Considering that there are uncertainties in respiration parameters of Table 1 and assumptions in Eqs.(1)-(3), the simulation is found to describe the behavior of gas concentration change pretty closely to experimental data, which can be helpful to elaborate the control scheme of the container operation. Variations in commodity mix and consumers' habit may be incorporated and tested to give versatile algorithm applicable to home storage of fresh produce. This work shows an initial potential of the container concept for creating and keeping MA range beneficial for refrigerated storage of fresh vegetables and fruits in home appliance for the limited storage time.

The gas composition of Fig. 3 kept the quality of stored products better than normal atmospheric air of the control (Table 2). The weight loss of all commodities, except for pak choi at 8 days and oyster mushroom at 16 days, was sig-

**Table 2.** Quality attributes of commodities placed and stored in the MA container at 3 °C according to atmospheric profile of Fig. 3[1]

| Quality attributes[2] | Commodity | Day 8 | | Day 16 | |
|---|---|---|---|---|---|
| | | Control | MA container | Control | MA container |
| Weight loss (%) | Spinach | 9.1±2.7[a] | 3.3±1.6[b] | | |
| | Pak choi | 1.1±0.6[a] | 0.6±0.8[a] | | |
| | Oyster mushroom | 5.2±0.1[a] | 3.9±1.0[b] | 8.4±3.6[a] | 6.0±1.2[a] |
| | Onion | 0.5±0.1[a] | 0.0±0.0[b] | 1.3±0.1[a] | 0.1±0.0[b] |
| | Strawberry | 9.0±3.6[a] | 0.5±0.4[b] | 18.3±11.7[a] | 1.5±0.2[b] |
| | Carrot | | | 0.9±0.2[a] | 0.0±0.0[b] |
| Chlorophyll content (mg/100 g) | Spinach | 66.0±3.5[b] | 72.0±2.2[a] | | |
| Ascorbic acid content (mg/100 g) | Pak choi | 95.3±7.2[b] | 124.2±14.8[a] | | |
| Firmness (N) | Oyster mushroom | | | 7.1±0.3[a] | 6.8±1.5[a] |
| Color 'L' | Onion | | | 82.8±1.1[a] | 81.2±1.0[b] |
| 'a' | | | | -1.9±1.3[b] | 0.0±0.9[a] |
| 'b' | | | | 10.9±0.9[a] | 9.2±0.9[b] |
| Aerobic bacteria count (log(CFU/g)) | Strawberry | | | 2.49±0.04[a] | 2.20±0.09[b] |
| Carotenoids (mg/100 g) | Carrot | | | 4.8±0.0[b] | 5.2±0.1[a] |

[1]Spinach and pak choi included initially in the product mix were taken out on day 8 of container opening, when carrot was loaded into the container. [2]Different alphabetical superscript letter after numeric data means significance at $\alpha$ of 0.05 for the same attribute at a storage time. Initial values in chlorophyll content of spinach, ascorbic acid content of pak choi, firmness of oyster mushroom, aerobic and aerobic bacterial count of strawberry, color values of onion and carotenoids of carrot were 78.4±3.7 mg/100 g, 137.7±10.9 mg/100 g, 7.0±0.4 N and 1.92±0.11 log(CFU/g), 81.8±2.0 ('L')/-0.5±1.8 ('a')/7.2±1.5 ('b') and 5.8±0.5 mg/100 g, respectively.

nificantly lower in the MA container than in control plastic packaging. There was a significant difference between two treatments in chlorophyll content of spinach and ascorbic acid content of pak choi after 8 days of storage. Oyster mushroom stored for 16 days were not significantly different in firmness between the treatments. Surface color of the stored onion for 16 days was closer to that of initial sample in the MA container than in control package. On 16 days of storage, the strawberries of the MA container were visually better than those of the control (not shown) and maintained significantly lower bacterial count (2.20 vs. 2.49 in log (CFU/g)). Carotenoids of cut carrot loaded at day 8 and taken out at day 16 were higher with MA container. On overall, the container system developed with proper control routine contributed to quality preservation of fresh produce mix by keeping appropriate MA range.

A concept of fresh produce MA container operating with scheme of initial hypobaric application, carbon dioxide supply and gas diffusion opening has been shown to work enabling to create and maintain MA beneficial for a typical product mix under scenario of consumer behavior. The developed container system could help to preserve the quality of the commodities contained in the container. Considering that there is wide variability of consumers' behavior in the commodities, opening/closing the container, filling/emptying the container and storage time, the concept may need to be tested for variety of conditions.

## Conclusion

A fresh produce container system was devised to be operated with control routine of vacuuming, $CO_2$ injection and diffusion tube opening for storage of fresh produce mix. The designed container with its operating routine could keep the desired MA and helped to preserve the quality of the contained commodities (spinach, pak choi, oyster mushroom, onion, strawberry and cut carrot) at 3°C under conditions used in households. Other manipulation of design variables may be tried or applied for diverse needs of product mixes or commodities of combination.

## Acknowledgment

This study was supported by the R&D Convergence Center Support Program of the Ministry of Agriculture, Food and Rural Affairs, Korea (Project #710013-03). Authors appreciate Soo Yeon Jung for measuring respiration of pak choi.

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투고: 2020.06.13 / 심사완료: 2020.07.16 / 게재확정: 2020.07.20