COMBINING MODIFIED ATMOSPHERE PACKAGING WITH CONTROLLED ATMOSPHERE FOR FRESH FRUITS AND VEGETABLES EXPOSED TO VARYING POSTHARVEST TEMPERATURES

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SUMMARY

A procedure to maintain proper levels of oxygen and carbon dioxide inside a modified atmosphere package (MAP) that is exposed to two different temperatures was designed and tested. The design procedure involved first designing the MAP for a surrounding air atmosphere at the higher temperature, then selecting a surrounding controlled atmosphere (CA) environment to use at the lower temperature. Two series of tests involving strawberries and snap beans were conducted to show the feasibility of the procedure. These products were stored at 7°C for 4 days then 19°C for 2 days to simulate storage/shipment and retail display, respectively.
Strawberries were stored in jars fitted with a short tube to regulate the flow of gases in and out of the jars. Snap beans were stored in commercially available, semipermeable plastic bags. The CA surrounding the MAP at 7°C helps to maintain the desired atmosphere inside the package by correcting for the change in product respiration rate due to the change in temperature.
A computer program was developed to predict gas concentrations inside a MAP, the required surrounding atmosphere, and the film or tube permeability ratios to achieve proper gas levels in a package. The program was used to predict atmospheres within the strawberry and snap bean packages.

Introduction

Fresh fruits and vegetables are perishable living tissues that continue to respire after harvest. The problem of spoilage of fresh fruits and vegetables is aggravated when commodities need to be shipped to distant markets. One way to reduce this problem and extend the shelf life of perishables is by promptly cooling and maintaining the produce at low temperatures [1, 2]. Another technique, especially as a complement to temperature management, is modification of the atmosphere surrounding the product to create a new atmosphere that usually has a lower level of O_2 and a higher level of CO_2. At these levels of O_2 and CO_2, the respiration rate of a commodity and consequently its deterioration will decrease, thereby extending shelf-life and reducing wastage of fresh produce during distribution and marketing [3].

In order to design a suitable MA package, several factors have to be considered: commodity type, temperature, optimum atmosphere (%O_2, %CO_2), respiration rate, product weight, and atmosphere outside the package [4]. The respiration rate depends on several factors such as surrounding gas concentrations, and type, maturity, and temperature of the product [5, 6].

Effect of temperature variations in MAP systems

Packed fruits and vegetables are usually exposed to varying surrounding temperatures during handling, transportation, storage and marketing. During marketing, the surrounding temperature is usually higher than during shipping or storage. The changes in surrounding temperature create a special problem in MAP design because the rate of respiration change is different than that of the permeabilities of MAP films. Due to this fact, it is difficult to provide an optimum atmosphere inside a package when the surrounding temperature is not constant. In order to maintain steady state gas concentrations in varying surrounding temperature conditions, the permeabilities of the packaging film or perforation must change at the same rate as the respiration rate over the temperature range of interest [6, 7]. Packages are normally designed for specific constant surrounding temperatures. All calculations of the internal atmosphere in sealed packages assume constant permeabilities of the film or perforation and respiration rates of the produce at some constant temperature [8]. Very little research has been done on modeling MAP systems for variable surrounding temperatures. Because of the difference in the rates of permeability and respiration change with temperature, a film that produces a favorable atmosphere at the optimal storage temperature may cause excessive accumulation of CO_2 and/or depletion of O_2 at higher temperatures, a situation that could lead to metabolic disorders [9, 10].

The objective of this study was to design and test a system that could maintain proper levels of O_2 and CO_2 when exposed to two different temperatures.

Materials and methods

The experiment was carried out by first storing the MA packaged products at 7°C/CA for four days and then at 19°C/ambient for another two days. The higher temperature simulated marketing conditions that involve display of produce in an ambient, open-air environment, while 7°C simulated transportation or storage conditions for which CA or pallet-scale MA technology is commercially available.

O_2 and CO_2 concentrations inside the MA packages were measured once each day throughout the experiments. Gas samples were analyzed for O_2 and CO_2 with a GowMac Series 580 gas chromatograph with thermal conductivity detector and a Hewlett Packard Model 3390A integrator. Two replicates of each sample were measured. Calibrations were done prior to each analysis of the gas samples using a standard mixture of 7.31% O_2 plus 7.18% CO_2.

System design procedure

The design of the system that can maintain proper atmosphere inside the MA package at those two temperatures followed the opposite route: first MAP was designed based on the higher surrounding temperature (19°C) and then the CA that will maintain proper atmosphere inside the MAP at the lower temperature (7°C) was selected.

System validation

1) Products tested

Strawberries and snaps beans were chosen to show the system feasibility because strawberries are highly suitable to MAP [11] and it has been shown that CA storage and shipping of snap beans avoids browning and delays senescence [12]. Recommended storage conditions for these commodities are 0-5ºC and 5-10% O_2 plus 15-20% CO_2 for strawberry and 4-7ºC and 2-3% O_2 plus 10-12% CO_2 for snap bean [12, 13, 14, 15]. 'Oso Grande' strawberries were harvested, forced-air precooled after harvest and brought by car (transit time = aproximately 2 h) to the Horticultural Sciences Department, University of Florida. The experiments were conducted beginning on the same day that the strawberries were harvested and precooled. 'Opus' snap beans were transported to the laboratory inside coolers from local farms, washed in chlorinated water (200 ppm) and forced-air cooled. They were kept overnight at 8°C until the start of the experiments.

2) MAP set up for strawberries and snap beans

Since no published information is available indicating the best atmosphere at typical retail display temperatures, the proper atmosphere at 19°C for strawberries and snap beans was assumed to be the same as at 7°C or lower temperature.

In order to obtain the proper atmosphere for strawberries, any package used must have a CO_2/O_2 permeability ratio of approximately one. Tubes or perforations have this permeability ratio. Therefore, a glass jar fitted with a small brass tube inserted in the lid was adopted as the container that would provide the modified atmosphere for the strawberries. The tube diameter and length were chosen based on preliminary experiments to obtain respiration rate data at 19ºC, published respiration rate data under different atmospheres [6], and by using a MAP computer program [16]. Three replicates of 3.8-liter jars containing 1 kg of strawberry fruit and fitted with a 12mm-diameter and 40mm-long brass tube were used. The effective permeabilities for O_2 and CO_2 at 7ºC and 19ºC for this tube were determined by Silva (1995) and are given in Table 1. The permeability ratio (PR) was 0.9 at both temperatures. The predicted respiration rate at 19ºC was 24.3 mL CO_2/kg.hr [6]. The predicted atmosphere inside the strawberry MA package was 10.0% O_2 + 11.3% CO_2 at 19ºC and 10.0% O_2 + 11.8% CO_2 at 7ºC.

Table 1

Permeability properties of the tube and film used in the experiments.

MAP system	**Tube (12mm×40mm) (Strawberries)**		**"Fresh Pak" film (Snap beans)**	
Temperature	7ºC	19ºC	7ºC	19ºC
O_2 Permeability	5.85×10^{-8} m^3/s	7.15×10^{-8} m^3/s	29,400 mL/(m^2.day)	43,008 mL/(m^2.day)
CO_2 Permeability	5.27×10^{-8} m^3/s	6.09×10^{-8} m^3/s	53,400 mL/(m^2.day)	76,008 mL/(m^2.day)
Permeability Ratio	0.90	0.85	1.82	1.77

For snap beans, a permeable plastic film bag ("Fresh Pak", SR Plastics, Denver, CO) was chosen based on the film permeability ratio requirement (≈1.4). The bag was made of polyethylene with activated earth plus ethyl vinyl acetate materials with a thickness of 38.10 μm and dimensions of 30.5×40.2 cm. The permeability values ($mL.m^{-2}.day^{-1}$) at 7ºC and 19ºC for O_2 and CO_2 (Table 1) were determined (Personal communication with Emond). Permeability ratio was about 1.8 at both temperatures. The plastic bags were thermosealed after being filled with snap beans. Because reliable information on snap bean respiration at various temperatures and atmospheres was not available at the time of the experiment, computer predictions for the gas concentrations inside the MAP were not possible. Several preliminary tests were done with different snap bean weights inside the bags at 19°C and, based on the results of these tests, a snap bean weight of 0.5 kg was chosen. Three replicates were used. Control samples of strawberries and snap beans were held continuously in air.

Results and discussion

Once the strawberry and snap bean experiments were carried out using the same CA master container at 7°C, a compromise atmosphere of 14.8% O_2 plus 8.3% CO_2 was used. The equilibrium inside the MA packages kept at 7°C was reached on the third day.

Concerning strawberry MAP, overall the O_2 level was maintained within the recommended range at both temperatures (Table 2). The CO_2 levels inside the strawberry jars at 7ºC and 19°C were maintained at about 13% and 16-19%, respectively (Table 2), being at 19°C much larger than those predicted. The change in gas levels and deviation from predicted gas levels at 19°C, especially on day 6**,** might be due to two possible reasons: a) error in the estimation of the respiration rate and b) fungal growth. Decay (gray mold due to *Botrytis cinerea*) was visible on some strawberries on the second day at 19°C. The fungal growth probably resulted in higher apparent respiration rate at 19ºC. In the control sample, decay was observed also at 7ºC. The strawberry decay observed on the second day at 19ºC was may be an indication that the CO_2 level at 7ºC, which was below the recommended level of 15%, may have allowed establishment of the fungal lesions that became visible upon transfer to 19ºC. Another possibility is that the MA at 19ºC, which was within the recommended range for strawberries at lower storage temperatures, was not sufficient to control gray mold development at 19ºC.

The 'Fresh Pak' bags reached a steady state atmosphere at 7ºC of about 3% O_2 plus 15% CO_2 (Table 2). Thus, under CA at 7°C, the CO_2 level went beyond the maximum recommended level of 12%. The O_2 level for snap beans slightly increased and the CO_2 level decreased from 15% to 12% when the snap bean bags were changed from 7°C/CA to 19°C/ambient air conditions (Table 2).

At 7ºC, due to different CO_2 requirements, the CO_2 was larger than the recommended value for snap beans and lower than the recommended value for strawberries. A slight increase in strawberry weight or a lower permeability tube would achieve better results for strawberries. No improvements in CO_2 levels could be made by changing the CA because an improvement in the snap bean 'Fresh Pak' bags would require a decrease in CO_2, while the strawberry jars needed higher CO_2.

This study has shown that it is possible to design MA packages to be put in CA containers for the purpose of shipping fresh commodities subjected to two different surrounding temperatures when the optimum storage conditions, product respiration rates and MAP permeabilities are known at both temperatures. This information is not always available. The results obtained were not as good as they could have been because the following two parameters were not exactly known: 1) optimum MA conditions at temperatures other than the optimum for transportation and storage, and 2) respiration rates at those temperatures and in various atmospheres. Although the proposed MAP/CA system was tested at only two temperatures, the basic approach should work when products are exposed to more than two temperatures. If, for example, between refrigerated shipment and retail display, the products are kept in a warehouse at another temperature, a second CA or a pallet-scale MAP system at the warehouse may be used to maintain the recommended levels of O_2 and CO_2 inside the MA packages.

Table 2
Atmospheres achieved inside MA systems for strawberries (1.0 kg) and snap beans (0.5 kg).

Experiment day	T (°C)	Surrounding atmosphere (%)		STRAWBERRY MAP[a] 12mm×40mm tube		SNAP BEAN MAP[b] "Fresh Pak" bag	
		O_2	CO_2	O_2	CO_2,	O_2	CO_2
0	7	14.8±0.4	8.3±0.3	20.8	0.0	20.8	0.0
1	7	14.8±0.4	8.3±0.3	13.6±1.0	8.2±0.7	-	
2	7	14.8±0.4	8.3±0.3	11.8±0.3	12.1±0.1	-	
3	7	14.8±0.4	8.3±0.3	11.0±0.3	13.1±0.1	2.6±1.1	15.9±2.5
4	7	14.8±0.4	8.3±0.3	11.0±0.4	13.3±0.4	3.2±0.9	15.1±1.3
5	19	Ambient air		9.2±0.7	15.8±0.8	3.9±1.3	12.1±3.9
6	19	Ambient air		6.9±0.7	19.2±1.4	5.2±0.7	9.0±1.6

[a] Recommended atmosphere for strawberries: 5-10% O_2, 15-20% CO_2
[b] Recommended atmosphere for snap beans: 2-3% O_2, 10-12% CO_2
Predicted atmosphere for strawberries: 10.0% O_2 at 7ºC in CA and 10.0% O_2 at 19ºC in ambient air.
11.8% CO_2 at 7ºC in CA and 11.3% CO_2 at 19ºC in ambient air.
Predicted atmosphere for snap beans: no predictions available because of unknown respiration rates.

Conclusions

By placing an MA package inside a CA environment, it is possible to maintain a desired atmosphere inside the package when this package is exposed to two different temperatures. Using this technique, it was shown that a desired atmosphere could be maintained, both during simulated shipping of mixed loads of strawberries and snap beans using MA packages inside a CA environment, and during subsequent simulated retail display in the MAP alone.

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