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Technical paper

Determination of Packaging Conditions for Selected Fresh Vegetables

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A method was proposed to determine the optimum packaging conditions for modified atmosphere packaging (MAP) of selected fresh vegetables. Each vegetable has an optimum gas composition for maintaining quality. When vegetables are packaged in a polymeric film, the in-package environment is expected to be maintained in this optimally selected composition. Broccoli and spinach respiration rates were measured in chambers in which the optimum gas composition was maintained. Optimum packaging conditions are a combination of surface area and gas permeability in which oxygen and carbon dioxide diffusing into the package are equal to the respiration rate. In this case, the inside and outside gases are equilibrated and the in-package gas composition is apparently maintained. The optimum gas conditions were calculated based on the respiration rate, and broccoli and spinach were stored under these conditions. Experimental results were in good agreement with the predicted optimum gas composition.

Keywords: MAP, respiration rate, gas permeability, packaging design

Modified atmosphere packaging (MAP) is an important technique for maintaining the quality of fresh produce (Kader *et al.*, 1989). MAP reduces the respiration rate by creating and maintaining the optimum gas condition, usually reduced O_2 and elevated CO_2 levels. Controlling the gas condition depends on the respiration rate of the produce, gas permeability, the surface area of polymeric film, and the storage temperature.

Many attempts have been made to model the dynamic changes in produce respiration within a package. Henig and Gilbert (1975) solved two simultaneous equations for the oxygen consumption and carbon dioxide evolution rates to simulate the gas concentrations in model tomato packages. Hayakawa *et al.* (1975) modified the model of Henig and Gilbert (1975), and obtained analytical solutions. These methods required experimental respiration rates as a function of the O_2 and CO_2 concentrations such that the O_2 consumption rate was constant at a 21-11.53% O_2 concentration and linearly decreased versus the O_2 concentration at a 4-11.53% O_2 concentration. Yang and Chinnan (1988a, b) determined the effect of the environmental gas compositions and storage periods on the respiration rate. They simulated the gas concentrations surrounding tomatoes using developed mathematical models. In these reports, 20 gaseous environments involving combinations of 4 levels of O_2 (5, 10, 15, and 20%) and 5 levels of CO_2 (0, 5, 10, 15, and 20%) were selected to obtain the respiration rate. These were difficult, time-consuming experiments for developing the respiration models. Cameron *et al.* (1989) developed a mathematical model for determining the O_2 consumption as a function of O_2 concentration (exponential type) by a tomato in a closed container. This model did not deal, however, with the effect of CO_2 concentration. Ishikawa *et al.* (1992) and Sato *et al.* (1993) developed respiration models as functions of storage time and O_2 and CO_2 concentrations using a multiple regression analysis. These models were constructed by an empirical approach and had limitations. Jurin and Karel (1963) predicted the atmospheric conditions attained under known packaging conditions by measuring the effect of oxygen and carbon dioxide concentrations on the respiration rate. This method could not, however, simulate changes in the in-package gas concentration. It did not require that the respiration rate be modeled and effectively predicted the steady-state gas composition.

Our objective was to propose a way to determine the optimum packaging conditions by measuring the respiration rate under the anticipated gas conditions.

Materials and Methods

Fresh produce Fresh broccoli (Hokkaido cv. Ryokurei) and spinach (Ibaraki cv. Solomon) were obtained from a local Tsuchiura market. Samples were placed in 10-30°C, 70-90% RH storage to equilibrate the experimental temperature and relative humidity until the start of the experiment. The weight of broccoli and spinach packaged with polymeric film was 200 g.

Controlled atmosphere storage A cylindrical container (acrylic resin, void volume: 2,000 ml) was used to measure the respiration rate. The container was hermetically sealed by an acrylic lid immediately after the vegetable was put into the container and a mixed gas (O_2: 2%, CO_2: 5%, N_2: 93%) was fed into it to obtain the optimum MAP condition.

Gas compositions inside the container were periodically measured for 3 h using gas chromatography (Hirata *et al*., 1993). The respiration rate of the vegetables was calculated from changes in the gas concentration.

Gas permeability of plastic film The gas permeability of the plastic films were determined using a Gasperm-100 (Nihon Bunko Inc., Tokyo). Low density polyethylene films were used for the MAP.

Results and Discussion

The changes in the O_2 and CO_2 concentrations in a cylindrical container containing air and the modified gas (low O_2 and high CO_2 concentrations) with fresh broccoli at 20°C were studied (Fig. 1). The oxygen consumption rate and carbon dioxide evolution rate were calculated from the changes in the gas concentration within the container, the void volume, and the incubation time. This decreased respiration rate under modified atmospheric conditions, as opposed to ordinary atmospheric conditions, extends the fresh produce shelflife. The optimum gas conditions for broccoli were 2-5% O_2 and 5% CO_2 (Dilley, 1978). The respiration rates at 2% O_2 and 5% CO_2 are calculated in Fig. 1(b). The O_2 consumption rate was 1,120 ml/day/kg and the CO_2 evolution rate was 1,346 ml/day/kg at 20°C.

When the O_2 diffusion into a pouch with 2% O_2 within the package equals the respiration rate of broccoli with 2% O_2, the O_2 concentration within the package is equilibrated with the outside and maintained at 2% O_2. The packaging condition is suitable for MAP, meaning that the optimum packaging condition can be calculated from the respiration rate alone under atmospheric conditions. According to Jurin and Karel (1963), the O_2 diffusion into the package with 2% O_2 is as follows:

$$Fo_2 = Ko_2 \times A \times (0.21-0.02) \quad (1)$$

where $Fo_2 = O_2$ diffusion into a package with 2% O_2 (ml/pkg/day)

Ko_2=gas permeability (ml/m^2/day/atm)

A=surface area (m^2)

At equilibrium, the O_2 diffusion into a package and the broccoli respiration rate should be equal. This is the optimum MAP condition:

$$Ro_2 \times W = Fo_2 \quad (2)$$

where Ro_2=respiration rate of broccoli with 2% O_2 (ml/day/kg)

W=sample weight (kg)

When the O_2 diffusion into a package with 2% O_2 exceeds the respiration rate, the gas concentration in the package changes to high O_2 and low CO_2 levels:

$$Ro_2 < Fo_2 \quad (3)$$

When the O_2 diffusion into a package is lower than the respiration rate, the gas concentration in the package changes to low O_2 and high CO_2 levels:

$$Ro_2 > Fo_2 \quad (4)$$

Under the studied packaging conditions (Table 1), the O_2 permeability for film a is 11,630 ml/m^2/day/atm and the film surface area is 0.096 m^2. The O_2 diffusion into the package is 211 ml/pkg/day with 2% O_2. The respiration rate of broccoli with 2% O_2 is 224 ml/day, because the O_2 consumption rate is 1,120 ml/day/kg and the packaged broccoli weight is 200 g. This packaging condition can be applied to equation (2). The O_2 permeability for film b is 11,630 ml/m^2/day/atm and the film surface area is 0.230 m^2. The O_2 diffusion into the package is 507 ml/pkg/day with 2% O_2. This packaging condition can be applied to equation (3). The O_2 diffusion into film c is 109 ml/pkg/day with 2% O_2. This packaging

Table 1. Packaging conditions and O_2 consumption rate of broccoli.

Film	Thickess (μm)	O_2 permeability (ml/m^2•day•atm)	Surface area (m^2)	O_2 diffusion into package (ml/pkg/day)
a	17.5±1.4	11630	0.096	211
b	17.5±1.4	11630	0.230	507
c	43.6±1.1	3600	0.160	109
			O_2 Consumption rate (ml/day)	
		Broccoli		224

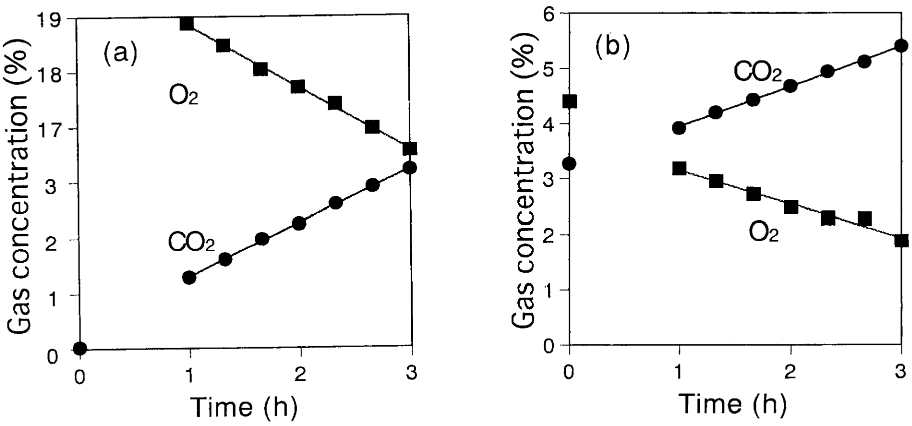

Fig. 1. Changes in gas concentration in containers of fresh broccoli.

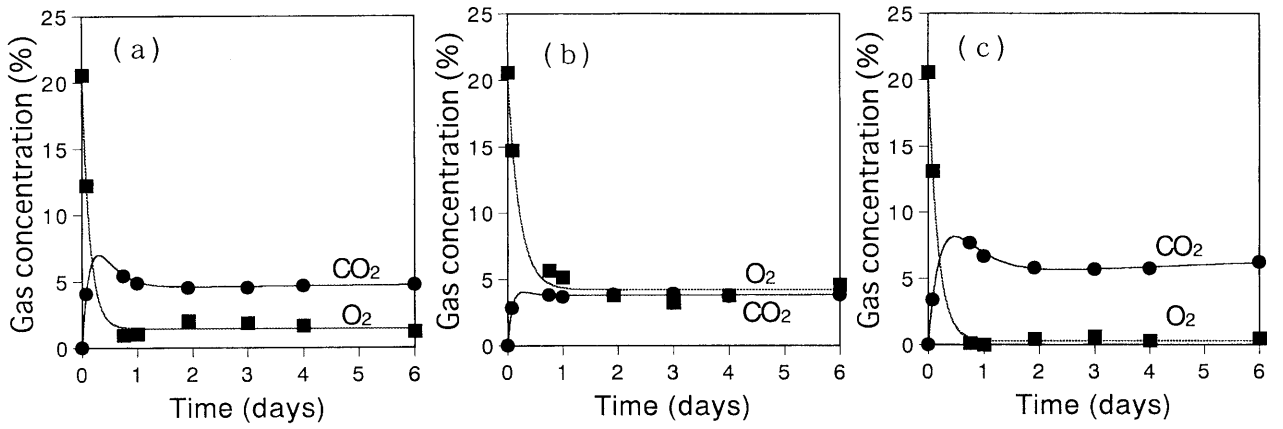

Fig. 2. Changes in gas concentration in film packages of fresh broccoli.

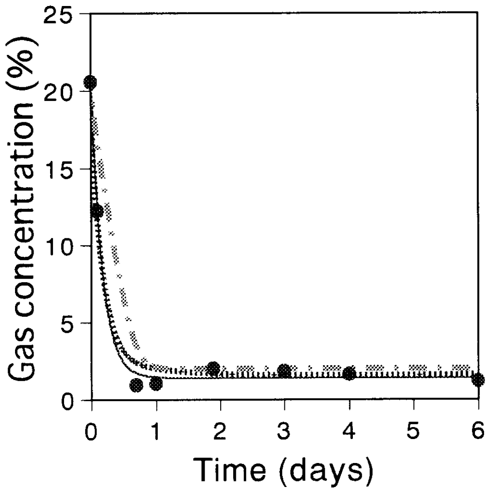

Fig. 3. Predicted and actual changes in oxygen concentration. —●— Actual data, IIIIII Predicted by model of Sato *et al.* (1993), —·—· Predicted by model of Henig and Gilbert (1975).

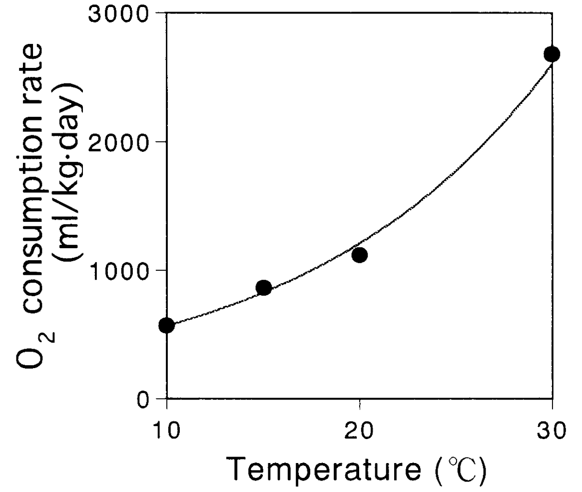

Fig. 4. Effects of temperature on oxygen consumption rate under 2% O_2.

condition can be applied to equation (4).

Figure 2 shows the changes in gas concentration within a pouch packaged under the conditions in Table 1. The gas concentrations within the pouch in Fig. 2(a) were equilibrated with 2% O_2 and 5% CO_2, and the experimental data agreed with the predicted results. This suggests that the simple design method proposed in this study may be useful in MAP design. The O_2 and CO_2 concentrations within the pouch in Fig. 2(b) were changed to approximately 4.5% and 4.0%, and experimental data agreed with predicted results. The difference in the O_2 partial pressure outside and inside of the pouch was 0.155 atm. The O_2 permeability with 4.5% O_2 was 414 ml/day, higher than that in Fig. 2(a). Kader *et al.* (1989) reported that the CA/MA conditions reduce the respiration rates with levels of O_2 and CO_2. The higher gas permeability of 414 ml/day suggests that the reduction in the respiration rate under this MAP condition is less than in Fig. 2(a) and equilibrated with the higher gas permeability. On the other hand, the O_2 and CO_2 concentrations within the pouch in Fig. 2(c) changed to 0.4% and 6.2%, and the experimental data agreed with the predicted results. The difference in the O_2 partial pressure was 0.206 atm and the O_2 permeability with 0.4% O_2 was 118 ml/day, suggesting that the respiration rate decreases based on the low O_2 and high CO_2 levels and must be equilibrated with the low O_2 permeability of 118 ml/day. It also suggests that anaerobic respiration may start at a low O_2 level.

The difference in the O_2 consumption rate under atmospheric conditions and air obtained in this experiment (1,699 ml/day/kg with air, 1,120 ml/day/kg with 2% O_2, and 5% CO_2) was smaller than that reported by Kader *et al.* (1989). The difference is assumed to depend on the effect of atmospheric conditions for controlling the metabolic activity of fresh produce. Moreover, a large difference in the respiration rate is supposed to have a more beneficial effect for maintaining the quality of fresh produce. In this experiment, the surface color of the control sample of broccoli packaged with perforated film changed after 2 days. Broccoli packaged under suitable packaging conditions (Fig. 2(a)), however, showed a changed surface color after 3 days. Ishikawa *et al.* (1996) reported that the change in the broccoli surface color started at 2 days after storage in air and 4 days after suitable MAP.

Table 2. Packaging conditions and oxygen concentration after 4 days at 20°C.

Film	O_2 permeability (ml/m^2•day•atm)	Surface area (m^2)	O_2 diffusion into package (ml/pkg/day)	O_2 concentration (%)
a	11630	0.147	307	1.78
b	11630	0.295	614	6.91
c	3600	0.147	95	0.23
			O_2 consumption rate (ml/day)	
	Spinach		253	

The short period that the surface color could be maintained in this study was assumed to be caused by the low degradation of the respiration rate under atmospheric conditions.

Figure 3 shows the change in the gas concentration simulated by two types of respiration models and the experimental data. The gas concentration changed to constant levels after one day. The difference between the models was not enough to affect the broccoli quality, suggesting that the method can be applied for simulating gas concentrations within the package. When the change in the gas concentration was simulated using respiration models, many respiration rates under different atmospheric conditions had to be measured for constructing the respiration model, requiring many samples and much time. Our MAP method, however, required only one respiration rate measured in a suitable gas environment for designing the optimum packaging.

Figure 4 shows that the relationship between the respiration rate with 2% O_2 and 5% CO_2 and storage temperature. The respiration rate depended on the storage temperature. Suitable packaging conditions including the type of film and surface area were calculated using equation 2, and broccoli was stored for model verification using the film. As a result, the gas concentration within the package was actually equilibrated at the predicted gas concentrations. If the dependence of the respiration rate on temperature was the same as that of the film gas permeability, the gas concentration was assumed constant and independent of temperature. The high gas permeability films were needed, however, for suitable packaging at high temperature. This suggests that the temperature dependence of the broccoli respiration rate was higher than that of film gas permeability.

Table 2 shows a packaging design suitable for spinach. The spinach respiration rate was relatively as high as broccoli and the O_2 consumption rate was 253 ml/day with 2% O_2 and 5% CO_2 at 20°C. The film packaging condition was designed to balance the respiration rate using equation 2. The gas concentrations in Table 2a changed to about 2% O_2 and 5% CO_2 as predicted. The steady state of the gas concentration in Table 2b involved high O_2 and low CO_2 levels, because the gas permeability of film b was higher than that of film a. The O_2 concentration significantly decreased and anaerobic respiration started with film c, because the gas permeability was lower than film a. This suggests that the packaging design in this study is applicable to spinach as well as broccoli.

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