Rapid Testing of Films for Modified Atmosphere Packages Using an Active Modification Technique

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Summary. It frequently takes days or weeks to determine if desired steady state concentrations of gases are reached in modified atmosphere packages of produce when atmospheres are modified by commodity respiration. We present a rapid method for testing packaging films and designs with active modification of atmospheres by vacuum and N₂ infusion. Reduction of O₂ concentration in produce packages and commodity tissues was completed within minutes by using several cycles of vacuum and N₂ infusion treatments. Produce packages were placed in a desiccator and subjected to repeated partial vacuums, each followed by infusion of N₂ to one atmosphere. Resulting O₂ concentrations in packages (polyethylene + ethyl-vinyl acetate additive) were dependent on the extent of vacuum and the number of evacuations. Within packages of tomatoes, O₂ concentrations of 8.3% ± 0.5% and 5.0% ± 1.0% were measured following two evacuations at 460 and 360 mm Hg, respectively. Three evacuations of cabbage and muskmelon packages at 460 mm Hg resulted in O₂ concentrations of 5.1% ± 1.4% and 5.0% ± 1.4%, respectively. Maintenance or deviation from actively established atmospheres by the film was determined within hours.

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Greater availability of packaging materials with a wide range of gas permeabilities has enhanced interest in the use of modified atmosphere packaging (MAP) to increase the postharvest life of fresh fruits and vegetables (Kader et al., 1989). Using a film with suitable gas permeabilities is crucial for the success of MAP. Once a film is selected, further optimization of a MAP design can be made by adjusting the film surface area and in-package commodity weight (Cameron et al., 1989; Henig and Gilbert, 1975; Kawada, 1981). Selection of an appropriate film and MAP design frequently are made by testing several films, each used with different packaging ratios (i.e., the ratio of film surface area to commodity weight in package).

When atmospheres are modified passively by produce respiration, days or weeks may be needed for in-package gas concentrations to reach steady state (Ballantyne et al., 1988; Geeson et al., 1985). Alternatively, if the approximate film type and packaging design is known or can be predicted from models, then the film and design can be tested rapidly by evacuating the commodity and package gases followed by infusion of a desired atmosphere. This approach is referred to as active modification. Commercially, there are packaging machines that have been designed to purge, fill, and seal produce packages with desired atmospheres (e.g., Multivac A300, Sepp Haggenmuller, Germany). Our objective was to develop an inexpensive, small-scale laboratory method for using the technique of active modification of atmospheres to rapidly test packaging films and MAP designs.

A schematic diagram of the apparatus used for active modification of atmospheres is shown (Fig. 1). A partially sealed (opening of 1 to 2 cm width) polyethylene + ethyl-vinyl acetate additive (PEVA) film package of produce was placed into a desiccator and then subjected to repeated exposures to partial vacuums (3 min) using a vacuum pump, followed by infusion of N_2 to atmospheric pressure. To ensure a uniform reduction of the O_2 concentration in the produce bag and the desiccator, the gas flow line in the desiccator was divided into two lines. One of the gas lines was inserted into the produce package, and the other was in the atmosphere of the container

Fig. 1 Schematic diagram of the apparatus used for active modification of atmospheres in produce package.

(Fig. 1). The rate of N_2 infusion was regulated by a flowmeter and stopped when pressure in the desiccator reached 1 atm. Three to 5 min at atmospheric pressure were allowed for N_2 to enter the commodity tissues following each infusion. After the final N_2 infusion, the opening on the package was clamped immediately and then sealed with an impulse sealer (State Mercantile Corp., Manhasset, N.Y.). The O_2 concentration in the package was measured with a gas chromatograph (Model 920, Varian Instruments) fitted with a thermal conductivity detector.

The method of actively modifying atmospheres in packages was used with mature green tomato (*Lycopersicon esculentum* Mill. 'Heinz 1350'), cabbage (*Brassica oleracea* 'Express'), and muskmelon (*Cucumis melo* L. var. *reticulatus* Naud. 'Mission'). The film surface area (A) and in-package commodity weight (W) of the packaging designs tested were: 1) muskmelon, $A = 1700 \text{ cm}^2$, $W = 1575 \pm 15$ or 1141 ± 49 g; 2) cabbage, $A = 1508 \text{ cm}^2$, $W = 1389 \pm 88$ g; and 3) mature green tomato, $A = 1303 \text{ cm}^2$, $W = 1300 \pm 28$ g. The permeability of films to O_2 was measured using a steady state method (Gong, 1992). The film used for packaging muskmelon and cabbage had a thickness of 1.6 mil (0.041 mm) and an O_2 permeability of $0.030 \text{ ml} \cdot \text{cm}^{-2} \cdot \text{h}^{-1} \cdot \text{atm}^{-1}$ at 10°C, and the film used for packaging tomato had a thickness of 1.3 mil (0.033 mm) and an O_2 permeability of $0.062 \text{ ml} \cdot \text{cm}^{-2} \cdot \text{h}^{-1} \cdot \text{atm}^{-1}$ at 20°C. Oxygen concentrations were measured over time for active and passive modification treatments.

Partial vacuums, number of evacuations, and O_2 concentrations

achieved are shown in Table 1. Actual O_2 concentrations achieved agreed closely with those calculated from the equation, $[O_2]_p = [O_2]_A (P/P_A)^n$, where $[O_2]_p$ is the O_2 concentration predicted in the package in percent, P is the low pressure resulting from partial vacuum applied in millimeters Hg, n is the number of evacuations, $[O_2]_A$ is the ambient O_2 concentration assumed to be 20.9%, and P_A is the ambient atmospheric pressure. Results demonstrate that initial in-package O_2 concentrations are predictable based on the extent of partial vacuum applied and the number of evacuations used.

In an empty desiccator (volume = 8 liters) it took ≈ 0.5 and 1.0 min to reduce the pressure to 460 and 360 mm Hg, respectively, in the two treatments used in experiments. Repeated exposures of commodities to low pressure (460 or 360 mm Hg) followed by N_2 infusion were used to reduce the O_2 concentration stepwise to the desired level rather than using one strong vacuum (e.g., 150 mm Hg). Passive atmosphere modification to achieve steady state O_2 concentrations took 4, 5, and 1 day(s) for muskmelon, cabbage, and tomato, respectively (Fig. 2). Use of the active modification technique established O_2 concentrations in minutes. Whether or not the film would maintain a desired O_2 level was determined within 1 day.

Results from this study show that the proposed active atmosphere modification system can be used to test efficiently packaging films and designs. Time should be allowed following film closure for changes to occur in the actively established initial gas concentrations. The maintenance concentration that follows then can serve as the

number to be evaluated for the appropriateness of the packaging parameters and for selecting new parameters if necessary. For example, if $4\% \pm 1\%$ is the desired O_2 concentration, as it is for muskmelon and tomato (Kader, 1980; Salunkhe and Wu, 1973), active modification would allow one to know within a day that an intermediate packaging ratio (i.e., A: W = 1.3 to 1.4 $cm^2 g^{-1}$) between the two tested for muskmelon should be used (Fig. 2A). In tomato packages (Fig. 2C), the actively established O_2 concentration, after an initial reduction to 4%, increased rapidly to $>6\%$, suggesting that a film with a lower O_2 permeability or that a smaller packaging ratio should be used. The tested design for cabbage (Fig. 2B) is appropriate because an in-package O_2 concentration of $\approx 3\%$ was maintained (Bohling and Hansen, 1977; Furry et al., 1981).

With tomato, passive modification allowed in-package atmospheres to reach steady state within 2 days, the shortest time among the three commodities (Fig. 2). However, experiments were conducted at temperatures higher than the recommended optimum storage temperatures for all three commodities. The time needed for passive modification to achieve steady state O_2 concentrations would be longer for packages kept at temperatures lower than those used in this experiment. Active modification allows one to obtain rapid determinations of the appropriateness of the packaging designs at the target temperature.

Packaging designs for MAP often need to be updated because packaging films vary in gas permeability from one batch to another, and respiration rates of commodities vary with cultivar, maturity, and season. Rapid testing or screening of packaging films and designs can be accomplished by active modification. In practice, most packers will have a specific packaging ratio

Fig. 2. Changes in O_2 concentrations following closure in packages of muskmelon (A), cabbage (B), and tomato (C) when atmospheres were modified passively or actively. Open symbols ($\circ$) and ($\square$) show active modification, closed symbol ($\bullet$) is passive modification. Packaging ratios (A : W) used were $1 \pm 0.1 \text{ cm}^2 \text{ g}^{-1}$, except ($\square$) for muskmelon, when the packaging ratio was $1.5 \pm 0.06 \text{ cm}^2 \text{ g}^{-1}$. Points represent means of three replications for muskmelon and tomato and four replications for cabbage. Vertical bars represent 1 SD. Bars smaller than symbols are not shown.

that can be adjusted only slightly. A film suitable for this design should be selected and tested, and then the packaging ratio should be adjusted to achieve the optimum steady state gas concentration.

Commercially, procedures for active modification of atmospheres include flushing packages with a desired gas mixture or drawing slight vacuums followed by injection of a gas mixture of the desired composition (Kader et al., 1985; Rizvi, 1988; Smith et al.,

1987). The method reported here enables the desired O_2 level in packages to be achieved quickly, easily, and predictably. The need for expensive gas mixtures containing a specific O_2 concentration is eliminated. Oxygen concentrations are not predictable if partial vacuums are pulled directly in sealed flexible packages because of the conformational changes in wrapping materials. The active modification technique described here allows equal reductions in atmospheric pressure inside and outside the partially sealed package during the vacuum treatment; it also gives the flexibility of using different partial vacuums combined with a varying number of evacuations to achieve the same desired in-package O_2 concentration. Overall, the method reported provides an approach and a research tool for rapid evaluation of MAP systems.

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Table 1. Concentrations of oxygen established actively in packages subjected to different partial vacuums compared with those obtained by calculation.

Commodity	Pressure (mm Hg)	Evacuations (no.)	O_2 concentration (%) ^a	
			Achieved	Predicted
Tomato	460	2	$8.3 \pm 0.5(3)$	7.6
	360	2	$5.0 \pm 1.0(3)$	4.7
Cabbage	460	3	$5.1 \pm 1.4(4)$	4.6
Muskmelon	460	3	$5.0 \pm 1.4(7)$	4.6

^aAchieved values are means $\pm$ SD. Numbers in parentheses indicate number of replications. Predicted values were calculated from the equation in the text.

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