Use of Passive and Semi-active Atmospheres to Prolong the Postharvest Life of Avocado Fruit

Elhadi M. Yahia and Gustavo Gonzalez-Aguilar

E. M. Yahia: DIPA, Facultad de Química, Universidad Autónoma de Querétaro, Querétaro QRO 76010 (Mexico)
G. Gonzalez-Aguilar: Centro de Investigación en Alimentación y Desarrollo, A.C., Hermosillo Sonora 83000 (Mexico)

(Received October 20, 1997; accepted December 15, 1997)

*Avocado (*Persea americana *Mill) fruits (cv. Hass) were individually wrapped in four low-density polyethylene films and one high-density polyethylene film, and kept at 5 °C and 85% relative humidity for 4 wk. Physical characteristics of the films were determined. Atmospheres were established by a passive and two semi-active methods. In the semi-active systems, CO_2 or a mixture of CO_2 and N_2 were introduced to the package immediately after sealing. In-package O_2, CO_2 and C_2H_4 content were analysed at 3 d intervals, and fruit were evaluated every week for texture changes, weight loss, and presence of chilling injury. Softening and weight loss were reduced by packaging, especially by using thicker films. Initial (semi-active) atmosphere modification reduced the accumulation of C_2H_4 in the packages, but did not result in any additional benefits in regard to fruit softening and weight loss.*

Keywords: *Persea americana*; postharvest; ethylene; modified atmosphere

Introduction

Avocado is a perishable fruit with a high metabolic rate resulting in a shelf-life of only 3 to 4 weeks at optimum temperature and relative humidity (1, 2). Cold storage delays ripening and prolongs storage life, but decay and chilling injury (CI) can result in serious problems during prolonged storage (3). The potential incidence of storage-related disorders such as vascular browning and mesocarp discolouration increases with fruit maturity (4).

Table 1 Characteristics of the films used for packaging of avocado fruit

Film	Thickness (mm)	Permeability	
		O_2 (mL · m^2 · s · Pa^1)	H_2O (g · m^2 · s^1 · Pa^1)
LDPE$_1$	0.066[a]	3.043×10^{-7}[b]	4.578×10^{-4}[c]
LDPE$_2$	0.043	6.168×10^{-7}	4.989×10^{-4}
LDPE$_3$	0.028	11.404×10^{-7}	5.099×10^{-4}
LDPE$_4$	0.015	16.585×10^{-7}	6.743×10^{-4}
HDPE	0.013	17.290×10^{-7}	5.647×10^{-4}

LDPE = low-density polyethylene; HDPE = high-density polyethylene.
[a] Each value is the mean of 20 replications.
[b] Each value is the mean of 3 replications.
[c] Each value is the mean of 6 replications

Table 2 Effects of modified-atmosphere packaging treatments on avocado fruit chilling injury ratings evaluated at different time intervals at 5 °C followed by 2 d at 20 °C

Treatments	Weeks			
	1	2	3	4
Control	0.50	1.13	1.90	1.60
LDPE$_1$				
Passive	0.00	0.00	0.38	1.00
Semi-active-1	0.13	0.13	0.50	0.50
Semi-active-2	0.13	0.00	0.38	0.50
LDPE$_2$				
Passive	0.00	0.00	0.25	0.13
Semi-active-1	0.00	0.00	0.25	1.40
Semi-active-2	0.00	0.25	0.38	0.50
LDPE$_3$				
Passive	0.00	0.00	0.25	1.25
Semi-active-1	0.25	1.13	2.00	1.38
Semi-active-2	0.00	0.00	0.88	1.13
LDPE$_4$				
Passive	0.25	0.13	1.50	2.10
Semi-active-1	0.00	0.13	2.00	2.00
Semi-active-2	0.25	0.63	1.30	2.40
HDPE				
Passive	0.25	0.13	0.75	1.40
Semi-active-1	0.00	0.13	1.60	2.90
Semi-active-2	0.25	0.25	1.10	1.40

LDPE = low density polyethylene; HDPE = high-density polyethylene.
See **Table 1** for the characteristics of the different types of LDPE

0023-6438/98/070602 + 05 $30.00/0

Atmosphere modification, by lowering the O_2 and/or increasing the CO_2 concentrations, has been shown to maintain the quality and extend the storage life of many fresh commodities (5). Modified-atmosphere packaging (MAP) refers to maintenance of an adequate atmosphere within a package, usually through the interaction of the respiration rate of the commodity and the gas permeation of the package film (6–8). When atmospheres are modified passively by the respiration of the commodity, days or weeks may be needed to reach steady-state in-package gas concentration (9, 10). Mathematical models could be used to select the type and characteristics of the film, and the design of the package, and to assure the desired atmosphere around the product (6, 11). Semi-active atmosphere modification, which refers to the initial removal or addition of a determined gas volume from the package, could maintain a more desirable atmosphere and thus further prolong the storage life of the fruit. The present study reports on the effects of passive and semi-active atmosphere modification on the storage life and quality of avocado fruit.

Materials and Methods

Mature avocado fruits cv. ‘Hass’ harvested from Uruapan, Michoacán, Mèxico were used. Upon arrival at the laboratory, fruit were sorted for uniformity and absence of defects, washed with chlorinated water (200 mg/L) at ambient temperature and dried. Sixteen groups of 32 fruits each were used for the different treatments. Single fruits were then sealed in four low-density

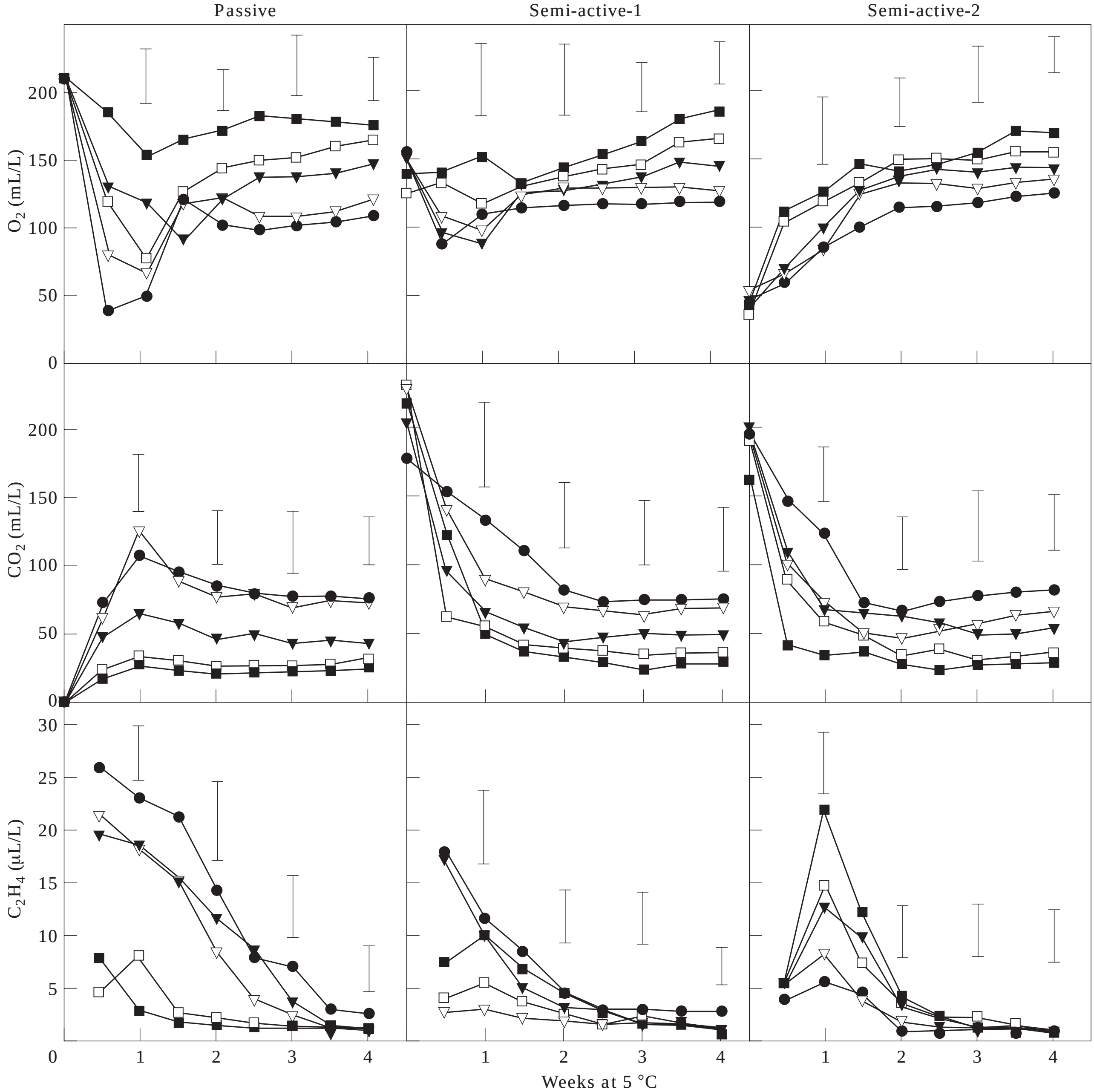

Fig. 1 In-package O_2, CO_2 and C_2H_4 of avocado fruit in a passive or 2 semi-active modified atmosphere systems. Vertical bars indicate SE of the mean. (•) LDPE-1, (▽) LDPE-2, (▼) LDPE-3 (□) LDPE-4, (■) HDPE.

polyethylene (LDPE) and one high-density polyethylene (HDPE) bags with a volume of 700 mL each (**Table 1**), and stored at 5 °C and 85% relative humidity (RH) for up to 4 weeks. LDPE films were numbered on the basis of their different characteristics (**Table 1**). Bags were sealed by use of an electric hot wire sealer. Three modified atmosphere systems were used: (a) passive system, where no gases were introduced to the packages other than the initial air, (b) semi-active-1 system, where 100 mL of CO_2 were injected into each package immediately after sealing, and (c) semi-active-2 system, where 100 mL of CO_2 and 200 mL of N_2 were injected into the packages immediately after sealing. The gases were introduced to the packages from compressed gas cylinders at a predetermined constant flow through a septum attached to each package with silicone sealant. A complete randomized design was used, and individual fruit were considered as replicates.

Film thickness was determined with a digital micrometer (Model DDT, E.J. Cady and Co., Wheeling, IL) with a range of 0 to 1.25 mm. Water vapour permeability was determined according to the method of the American Society for Testing and Material (12). Oxygen permeability was measured by the use of an OX-TRAN 100A (Mocon, Modern Controls Inc., Minneapolis, MN). LDPE films used ranged in thickness from 15 to 66 μm. Permeability of these films to oxygen varied from 3.043×10^{-7} to 16.585×10^{-7} mL $O_2/(m^2.s.Pa)$. Water vapour permeability ranged from 4.578×10^{-4} to 6.743×10^{-4} g $H_2O/(m^2.s.Pa)$. The HDPE film used had the lowest thickness, and highest O_2 permeability and had a relatively high rate of water vapour permeability (**Table 1**). In-package concentrations of O_2, CO_2 and C_2H_4 were measured at 3-d intervals by withdrawing air samples through the septum using a hypodermic syringe. In-package CO_2 content was determined with an infrared CO_2 analyser (Horiba Model PIR 2000, Horiba Instruments Inc., Irvine, CA). Oxygen content in the package was measured with a portable O_2 analyser (Mocon LC 700F Toray Engineering Co., Japan). The accumulation of C_2H_4 in the package was analysed with a Hatch Carle series 400 gas chromatograph with an FID detector.

Fruit (eight fruits/treatment) were evaluated every week for weight loss and flesh firmness. Flesh firmness was determined on six points in different positions of each fruit (skin removed), using a firmness tester (Chatillon DFG 50, John Chatillon & Sons, Inc., New York, NY) equipped with an 8-mm tip. Presence of CI was evaluated after the fruit had been held for 2 d in air at 20 °C and 75% RH after removal from storage. CI was expressed as a general grey discolouration of the mesocarp, and assessed according to the following scoring system: 0, no symptoms; 1, very slight; 2, slight; 3, moderate; 4, severe; and 5, very severe. Statistical analysis was performed using SAS's personal computer software package version 6.03 (13). Data were subjected to an analysis of variance and the means of the

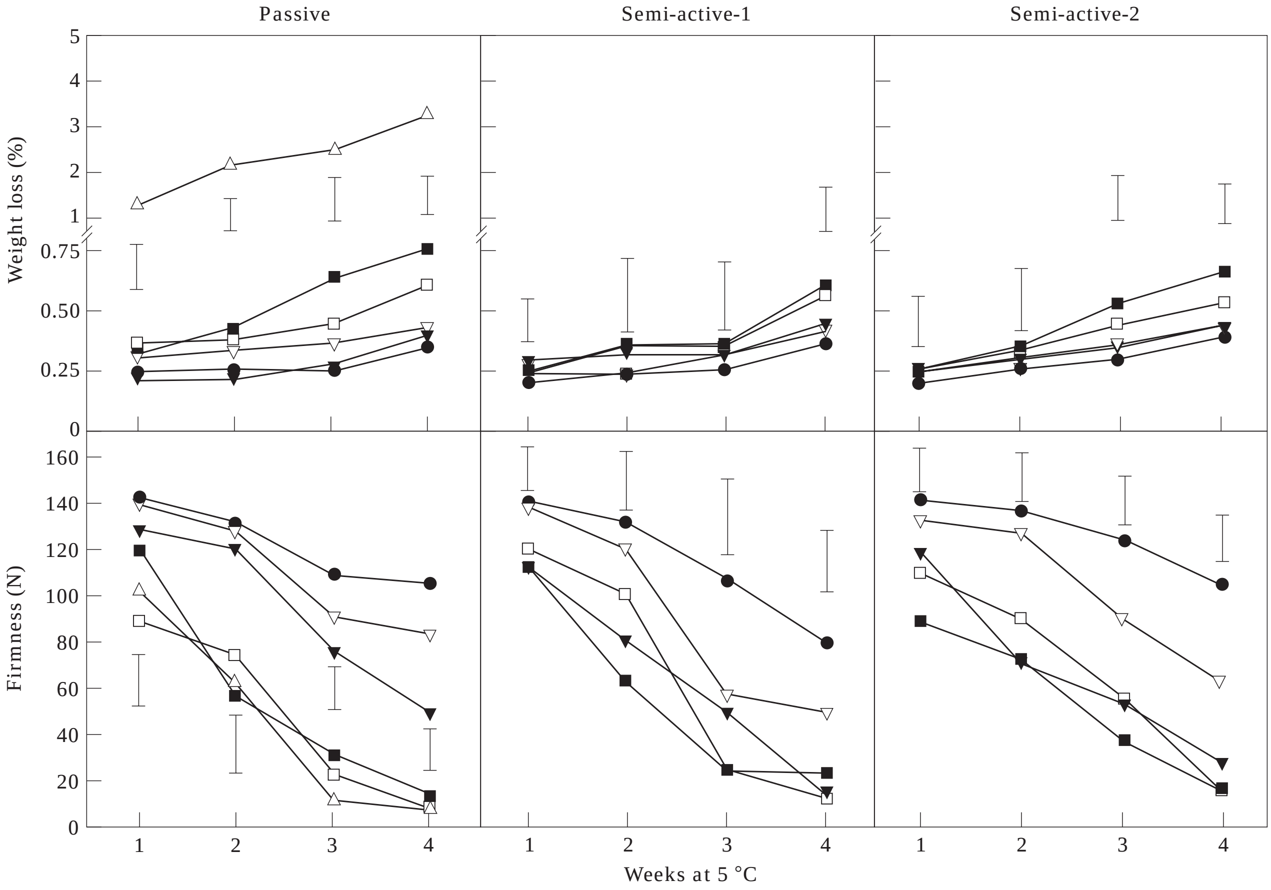

Fig. 2 Weight loss (%) and firmness of avocado fruit kept in a passive or 2 semi-active modified atmosphere systems. Vertical bars indicate SE of the mean. (△) Control, (•) LDPE-1, (▽) LDPE-2 (▼) LDPE-3 (□) LDPE-4 and (■) HDPE.

treatments were compared using standard error of the mean.

Results and Discussion

In-package O_2 concentrations in the passive system after 2 d were less than 5 mL/L in $LDPE_1$, 75 in $LDPE_2$, 130 in $LDPE_3$, 120 in $LDPE_4$, and 185 mL/L in HDPE (**Fig. 1**). They decreased thereafter (except in $LDPE_1$) and increased after 1 week, becoming stable after 2 weeks at about 100 in $LDPE_1$, 110 in $LDPE_2$, 140 in $LDPE_3$, 160 in $LDPE_4$, and 175 mL/L in HDPE.

In-package CO_2 content was highest in $LDPE_1$ and $LDPE_2$ (ca. 80 mL/L) and lowest in $LDPE_4$ and HDPE (ca. 20 to 30 mL/L) after 2 days in storage (**Fig. 1**). $LDPE_3$ had an intermediate CO_2 content of about 50 mL/L.

The introduction of 100 mL CO_2 (semi-active-1) or 100 mL CO_2 and 200 mL N_2 (semi-active-2) to the package resulted in less variability in the initial atmosphere and reduced the O_2 content and increased the CO_2 levels in this atmosphere (**Fig. 1**). The use of semi-active-1 and semi-active-2 systems generated an initial atmosphere with low O_2 (35 to 50 mL/L) and high CO_2 (165 to 200 mL/L) concentrations. The introduction of 100 mL CO_2 (semi-active-1) to the package maintained an atmosphere with ≤ 150 mL/L O_2, except in $LDPE_4$ and HDPE, after 3 weeks. In-package O_2 contents increased steadily and were about 120 in $LDPE_1$, 130 in $LDPE_2$, 145 in $LDPE_3$, 160 in $LDPE_4$, and 170 mL/L in HDPE after 2 weeks. The initial CO_2 content was very high (180 to 230 mL/L), but decreased continuously reaching 70 mL/L for $LDPE_1$ and $LDPE_2$, 50 mL/L in $LDPE_3$, 35 mL/L in $LDPE_4$, and 25 mL/L in HDPE, after 2 weeks. In-package CO_2 contents (semi-active-1) decreased steadily to about 80 in $LDPE_1$, 60 in $LDPE_2$, 50 $LDPE_3$, 35 in $LDPE_4$ and 25 mL/L in HDPE, after 2 weeks. In-package O_2 content in the semi-active-2 system increased steadily to about 120 in $LDPE_1$, 130 in $LDPE_2$, 140 in $LDPE_3$, 160 in $LDPE_4$ and 175 mL/L in HDPE after 2 weeks. In the semi-active-2 system, the CO_2 content decreased in a similar pattern to the semi-active-1 system and after 2 weeks reached concentrations of 80 in $LDPE_1$, 60 in $LDPE_2$, 50 in $LDPE_3$, 40 in $LDPE_4$, and 30 mL/L in HDPE.

In-package ethylene accumulation was highest after 2 d, declined to about 1 to 3 µL/L after 2 weeks, and remained almost constant throughout the experimental period in the three atmosphere systems. In the passive MAP, ethylene accumulation was higher than in both semi-active systems. In all three systems the accumulation of ethylene was higher as the thickness of the films increased. The initial modification of the atmosphere (semi-active systems) reduced the accumulation of ethylene in the packages, but no differences were observed between the three MAP systems in the last week of storage.

MAP resulted in significant reduction of fruit weight loss (**Fig. 2**). Wrapped fruit lost significantly less weight than unwrapped fruit and maintained a good visual appearance during the storage periods, even after being held for 2 d at 20 °C. Reduction of fruit firmness was observed in films with more than 0.03 mm of thickness. The introduction of either 100 mL CO_2 or a combination of 100 mL CO_2 and 200 mL N_2, did not result in any further reduction in the losses of both fruit firmness or fruit weight compared to the passive system.

In all treatments used, the ratings for CI symptoms were very low (**Table 2**). The CI ratings were similar during the first 2 weeks of storage in all treatments, except for $LDPE_1$ and $LDPE_2$. Fruit wrapped in films with more than 0.03 mm of thickness showed the least symptoms of CI, followed by fruits wrapped in HDPE, unwrapped (control), and those wrapped in $LDPE_4$. These results indicate that MAP is effective in reducing CI incidence in avocado fruit.

Lower incidence of decay deterioration was observed, with the highest decay in the control fruits (data not shown).

Similar results were reported by previous authors (3, 14, 15). ‘Hass’ avocados sealed in polyethylene bags of unknown characteristics and stored at 20 or 30 °C for 4 to 11 d stayed firmer and apparently did not ripen while in the bags (14). Atmospheres developed in the bags were from 24 to 62 mL/L O_2, 65 to 89 mL/L CO_2, and 0.1 to 12.7 µL/L ethylene. The presence of $KMnO_4$ in the bags had no effect on O_2 and ethylene levels, but significantly decreased the CO_2 levels. The CO_2 is absorbed by the activated alumina (Al_2O_3) used as the $KMnO_4$ support. The failure of the $KMnO_4$ to reduce the ethylene concentration was probably due to high temperature. Abnormal ripening was observed when the storage temperature was high and the period exceeded 8 d. ‘Hass’ and ‘Fuerte’ fruits individually sealed in polyethylene bags (0.05 mm thickness) and stored at 4 or 7.5 °C showed little or no CI symptoms compared to control fruit (3). The atmosphere inside these bags had 30 to 70 mL/L CO_2, 20 to 60 mL/L O_2, and up to 2.5 µL/L of ethylene. Oudit and Scott (15) reported a considerable extension in the storage life of ‘Hass’ avocados sealed in polyethylene bags. Decay development in avocado fruit sealed in polyethylene bags was considered to be a problem by some researchers (16), but not by others (17).

Conclusions

MAP decreased the incidence of fruit decay and CI symptoms, and prolonged the postharvest life of avocado fruit by reducing weight loss and flesh softening. The initial modification of the atmosphere by introducing 100 mL CO_2 or 100 mL of CO_2 and 100 mL of N_2 to the packages reduced the accumulation of C_2H_4 but did not result in any additional benefits, probably owing to the short period in which the initially modified atmosphere was maintained. The use of films with lower permeability to these gases could maintain the initially modified atmosphere for longer periods. The appropriate use of these semi-active MAP systems could be beneficial in substantially increasing the postharvest life of avocado fruit.

References

1 Yahia, E. M. and Baez, R. Manejo postcosecha de frutas subtropicales. In: Yahia, M. E. and Higuera, I. (Eds), *Fisiología y Tecnología Postcosecha de Productos Hortícolas*. México: Limusa/Noriega Editores, pp. 189–205 (1992)

2 Hardenburg, R. E., Watada, A. W. and Wang, C. Y. The commercial storage of fruits, vegetables and florist and nursery stocks. United States Department of Agriculture (USDA) Agriculture Handbook No. 66. USDA, Agric. Res. Serv (1986)

3 Scott, K. J. and Chaplin, G. R. Reduction of chilling injury in avocados stored in sealed polyethylene bags. *Tropical Agriculture (Trinidad)*, **55**, 87–90 (1978)

4 Cutting, J. G. M., Bower, J. P. and Wolstenholme, B. N. Effect of harvest date and applied ABA on browning potential of avocado fruit. *Journal of Horticultural Science*, **63**, 509–515 (1988)

5 Kader, A. A. Biochemical and physiological basis for effects of controlled atmospheres on fruits and vegetables. *Food Technology*, **40**, 99–100, 102–104 (1986)

6 Kader, A. A., Zagory, D. and Kerbel, E. L. Modified atmosphere packaging of fruits and vegetables. *CRC Critical Reviews in Food Science and Nutrition*, **28**, 1–30 (1989)

7 Labuza, T. P. and Breene, M. Application of active packaging for improvement of shelf life and antinutritional quality of fresh and extended shelf life foods. *Journal of Food Protection and Preservation*, **13**, 1–69 (1989)

8 Yahia, E. M. and Rivera-Domínguez, M. Modified atmosphere packaging of muskmelon. *Lebensmittel-Wissenschaft und-Technologie*, **25**, 38–42 (1992)

9 Ballantyne, A., Stark, R. and Selman, J. D. Modified atmosphere packaging of shredded lettuce. *International Journal of Food Science and Technology*, **23**, 267–274 (1988)

10 Geeson, J. D., Browne, K. M., Maddison, K., Shepherd, J. and Guaraldi, F. Modified atmosphere packaging to extend the shelf life of tomatoes. *Journal of Food Technology*, **20**, 339–349 (1985)

11 González, G., Yahia, E. and Hasa, M. Empaque de mango en atmósferas modificadas y predicción de la atmsófera dentro del empaque utilizando modelos matemáticos. *Revista de Ciencias Alimentarias (México)*, **1** (3), 1–5 (1991)

12 ASTM. WVTR of materials in sheet form. American National Standard E. 96-22. Philadelphia: American Society for Testing and Material, pp. 236–237 (1979)

13 SAS Institute. *SAS User's Guide: Statistics. Version 6.03*. Cary, NC: SAS Institute (1988)

14 Chaplin, G. R. and Hawson, M. G. Extending the postharvest life of unrefrigerated avocado (*Persea americana* Mill) fruit by storage in polyethylene bags. *Scientia Horticulturae*, **14**, 219–226 (1981)

15 Oudit, D. D. and Scott, K. J. Storage of Hass avocados in polyethylene bags. *Tropical Agriculture (Trinidad)*, **50**, 241–243 (1973)

16 Aharoni, Y., Nadel-Schiffmann, M. and Zaubermann, G. Effects of gradually decreasing temperature and polyethylene wraps on the ripening and respiration of avocado fruits. *Israel Journal of Agricultural Research*, **18**, 77–82 (1968)

17 Thompson, A. K., Mason, G. F. and Halkon, W. S. Storage of West Indian seedling avocado fruits. *Journal of Horticultural Science*, **46**, 83–88 (1971)