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# Prolonged storage of 'Hass' avocado fruit using modified atmosphere packaging

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## Abstract

An attempt was made to characterize prolonged modified atmosphere (MA) storage of 'Hass' avocados (*Persea americana* Mill.) for commercial application in terms of optimal thickness of polyethylene (PE) bags, optimal storage temperature, appropriate ratio between the amount of fruit and the size (surface area) of the bags, and maximal storage period without chilling injury (CI). The best result was obtained with 30 μm PE bags (40 × 70 cm) containing 3.2 kg fruit and stored at 5°C. The oxygen level in these bags was reduced to approximately 4%, the accumulated carbon dioxide reached values of around 5% at storage temperatures of either 5 or 7°C, while the lowest ethylene concentration was detected at 5°C. Development of CI during storage, manifested as pulp discolouration, was not significantly affected by the different thickness of PE bags tested (30–50 μm). Fruit stored at 5°C remained firmer than those stored at 7°C, and the fruit keeping quality in completely sealed bags providing MA was superior to that in perforated bags or unwrapped controls. Storage in sealed PE bags also reduced weight loss and slowed down the development of black pigmentation in the peel; nevertheless, the fruit peel reached its characteristic dark colour at full softening. This work demonstrates for the first time the potential for long-term storage (up to 9 weeks) of 'Hass' avocado fruit under MA in a commercial size package. © 1997 Elsevier Science B.V.

*Keywords:* *Persea americana*; Hass; Avocado; Modified atmosphere; Polyethylene bags; Chilling injury

## 1. Introduction

Modified atmospheres (MA) are created when fruit is sealed in bags made of polyethylene (PE) films with relatively-low permeability to gases. Consequently as the fruit respires, the $O_2$ level

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decreases and the $CO_2$ level increases in the bags (Day, 1994). Under such atmospheric conditions the respiration rate of the fruit is decreased and the ethylene climacteric rise is delayed (Biale, 1964; Meir et al., 1995), thereby retarding ripening and deterioration processes. In addition, MA conditions (low $O_2$ and high $CO_2$) inhibit the expression of hydrolytic enzymes associated with avocado fruit softening (Kanellis et al., 1989). However, the complete physiological basis for MA storage is not yet fully understood.

The few studies that have been carried out on MA storage of avocado fruit have only involved individual fruit packaging, and have thus provided limited information on the effect of packaging on several quality parameters, particularly fruit firmness and appearance of CI symptoms (Aharoni et al., 1968; Oudit and Scott, 1973; Scott and Chaplin, 1978; Gonzales et al., 1990; Truter et al., 1991; Eksteen et al., 1992). In addition, little data was reported concerning the changes in the gas composition within the package during storage, and in most cases the package atmosphere was sampled only at the end of the storage period, which did not exceed 6 weeks.

When designing an MA system, the aim is to achieve in the package an equilibrium at which the particular commodity will be surrounded by its specific optimal atmosphere and relative humidity. Such an equilibrium is determined by the following factors: (1) stage of maturity of the commodity and its respiration rate; (2) storage temperature; (3) type of film in respect of its thickness and permeability to $O_2$, $CO_2$, and water vapour; and (4) the ratio between film surface area and fruit volume (or weight) (O'Beirne, 1991).

There are several reports showing a limited success of controlled atmosphere (CA) storage of various avocado fruit varieties for 5–9 weeks (Hatton and Reeder, 1972; Barmore and Rouse, 1976; Arpaia et al., 1990; Hatton and Spalding, 1990; Meir et al., 1995). The best results were obtained when fruit was stored at between 5 and 7°C, under an atmosphere of 2–3% $O_2$ and 8–10% $CO_2$. As of today, mostly for technical and economical reasons, there are limits to the commercial application of CA for commercial purposes (Arpaia et al., 1990; Eksteen et al., 1992).

Attempts to store avocado fruit under MA have shown that fruit ripening was delayed when individually sealed fruit was kept at 20–22°C (Chaplin and Hawson, 1981; Joyce and Shorter, 1992). When storage temperatures varied between 7 and 14°C and the $O_2$ and $CO_2$ concentrations in the bags varied between 2–6 and 3–7% respectively, fruit retained good quality for up to 7 weeks (Scott and Chaplin, 1978). When $O_2$ concentrations within the bag exceeded 9%, fruit became soft during 4 weeks of storage (Gonzales et al., 1990). In a simulated shipment of cartons containing 4 kg fruit sealed in PE bags, 'Fuerte' fruit was stored for 3 weeks and 'Nabal' fruit for 6.5 weeks (Aharoni et al., 1968). The $O_2$ and $CO_2$ concentrations monitored within these bags varied between 3 and 8%, and 6 and 8%, respectively.

Based on these results, it seems that MA storage of avocado fruit in appropriate PE bags kept within commercially used cartons (3–4 kg), would be relatively simple and economically feasible to achieve in standard cold storage rooms and during sea shipments. The purpose of the present study was, therefore, to characterize MA storage of 'Hass' avocado fruit in order to advance further our knowledge and enhance the possibilities of using this storage method on a commercial scale. We determined the optimal storage temperature and the appropriate relationship of 'Hass' fruit quantity to bag size, during storage for up to 9 weeks. Various parameters of fruit quality and chilling injuries were assessed at the end of the cold storage period and after ripening under shelf-life conditions.

## 2. Materials and methods

'Hass' avocado fruit (*Persea americana* Mill.) was used during two harvesting seasons. The fruit was stored at 5°C under about 95% RH for the first 2 days after harvest before being sealed in bags and transferred to storage at various temperatures. All fruit were dipped in 0.2% 'Sportak' (Prochloraz-*N*-propyl-*N*-[2-(2,4,6-trichlorophenoxy) ethyl] imidazole-1-carboxamide) solution, and dried at 20°C for 30 min before storage. In the first experiment, fruit was stored at 5 or 7°C under about 95% RH for 5 or 7 weeks. In addition, 15 unwrapped fruit were kept under shelf-life conditions (20°C) without storage, as controls. The following packaging treatments (five replicates of each) were examined at each storage temperature: (1) 15 fruit without bags; (2) 15 fruit in perforated 30 $\mu$m polyethylene (PE) bags (about 40 holes, each 5 mm in diameter); and (3) fruit in sealed PE bags of 30, 40 or 50 $\mu$m thickness. The number of fruit in the sealed bags of different thicknesses was 5, 10 or 15. All the sealed and perforated bags were identical in size (40 × 70 cm) and, therefore, in surface area. Three layers of paper were placed at the bottom of each bag to absorb excess condensation water which accumulates as a result of temperature fluctuation during storage. Both unwrapped and sealed fruit were stored in cartons.

In the second experiment, fruit were stored at 5 or 7°C for 9 weeks as described for the first experiment, with and without sealed bags. The sealed bags were 30 $\mu$m in thickness and of the same size (40 × 70 cm), and contained 22 fruit weighing 3.2 kg on average. Each treatment included four packages as replicates. Four unwrapped packages of 22 fruit were used as controls.

To each sealed bag was glued a silicone rubber patch, through which the internal atmosphere was sampled periodically during storage, using a 10-ml plastic syringe. Concentrations of $O_2$, $CO_2$ and ethylene in the samples were determined by gas chromatography: $O_2$ and $CO_2$ with a Packard model 839 gas chromatograph equipped with a thermal conductivity detector and a CTR-I column containing a molecular sieve and Poropak Q; ethylene with a Varian 3300 gas chromatograph equipped with an activated-alumina column and a flame ionization detector (FID).

In the two experiments, the bags were removed before fruit was transferred to shelf-life conditions (20°C) to ripen. Respiration and ethylene production rates of the fruit during the shelf-life period were determined by enclosing single fruit in 2-l jars for 1 h, and sampling the headspace atmospheres of the jars with a plastic syringe, through a rubber septum. Carbon dioxide and ethylene concentrations in the samples were determined by gas chromatography as described above.

The firmness of the fruit was expressed as Newtons (N) required to penetrate unpeeled fruit, and determined with a ‘Chatillon’ pressure tester equipped with a conical probe, 6 mm in diameter. Firmness determinations were made at the beginning of the experiments, during the cold-storage period (5 or 7°C) and during storage under shelf-life conditions (20°C). Each firmness determination was performed on two opposite sides of the fruit’s equator with samples of ten fruit, and standard errors (S.E.) calculated. The examinations continued until complete softening (defined as resistance to penetration lower than 15 N) of all the fruit was achieved. This degree of firmness is defined as normal eating ripeness. Weight loss was calculated as the fruit weight at the beginning of the experiment, after different storage periods and during ripening under shelf-life conditions.

Chilling injury (CI) to the pulp, manifested as grey discolouration, was evaluated visually after cutting the soft fruit. Fruit was cut either after 4 days at shelf-life (first experiment), or when their firmness was $\leq 15$ N (second experiment). The CI assessment was based on four stages of pulp discolouration, ranging from 1 to 4 as follows: 1, no discolouration; 2, light grey discolouration in no more than 30% of the pulp; 3, light grey discolouration in more than 30% of the pulp or intermediate brown discolouration; and 4, severe dark to black discolouration. Results were expressed as CI index calculated using the following formula:

$$\text{CI index (between 1 and 4)}$$
$$= \frac{\text{(CI level)} \times \text{(Number of fruit at the CI level)}}{\text{Total number of fruit in the treatment}}$$

Since ‘Hass’ avocado peel changes colour from green to a characteristic purple-black during normal ripening, peel colour in this cultivar was evaluated on a 1–5 scale, as follows: 1, full green; 2, beginning of colour change (green-brown); 3, colour change (half green and half brown); 4, brown with traces of green; and 5, dark fruit (purple-black), characteristic of a ripe ‘Hass’ fruit. This ripening index was calculated according to a

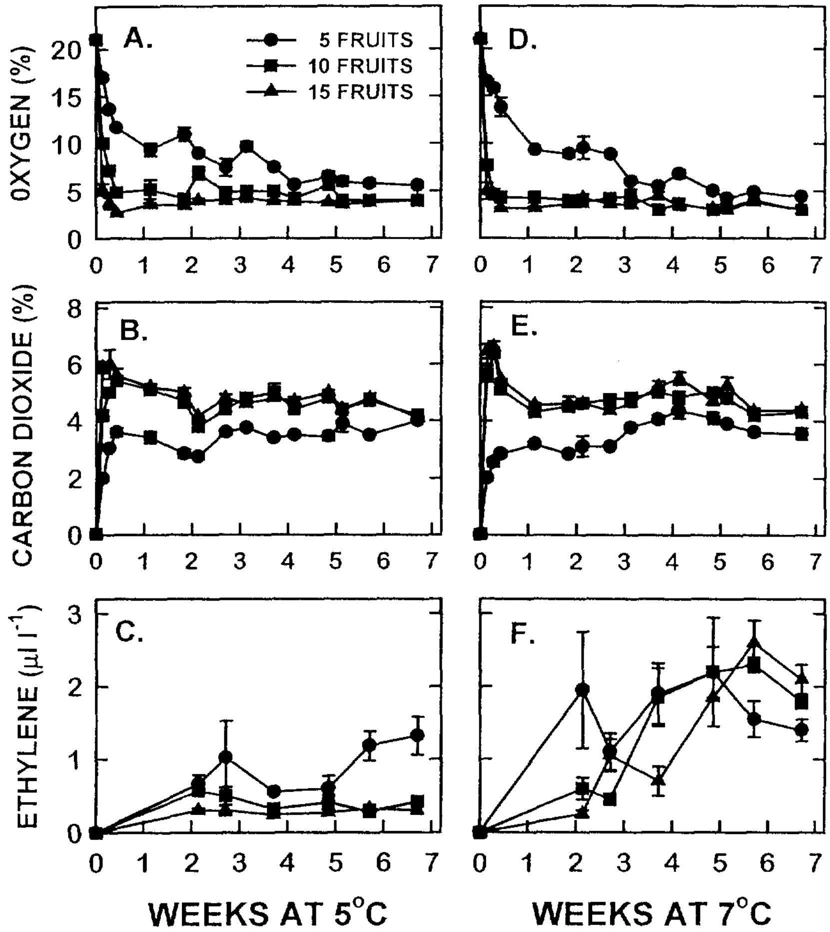

Fig. 1. Pattern of changes in oxygen (A,D), carbon dioxide (B,E) and ethylene (C,F) concentrations in 30 µm polyethylene bags containing various quantities of 'Hass' avocado fruit, during storage at 5 or 7°C for 7 weeks. Bags (40 × 70 cm) with 5 (●), 10 (■) or 15 fruit (▲) at an average weight of 205 g per fruit, were used. The values represent means ± SE of four bag replicates (Exp. 1).

formula similar to that presented above for the CI index. At the end of the various storage and shelf-life periods, ripe fruit with no discolouration from all treatments were tasted by a team of three specialists, to score fruit for their acceptability as edible.

## 3. Results

The effects of fruit quantity within the sealed bags and storage temperature, on the composition of the atmosphere in 30 µm bags, are presented in Fig. 1. Since no significant effect of bag thickness on atmosphere composition was found (data not shown), these results also represent the changes which took place in bags of 40 and 50 µm thickness. It can be seen clearly that at both storage temperatures, the reduction in $O_2$ concentration (Fig. 1A,D), and the increase in that of $CO_2$ (Fig. 1B,E) were achieved more quickly as fruit quantity within the bag increased. As a result, the equilibrium of the gas atmosphere in these bags was reached sooner. The gas concentrations obtained at equilibrium were similar for 10- or 15-fruit bags, reaching 3.5–5% $O_2$ and about 5% $CO_2$ within 1 week. However, in bags containing only five fruit, the decrease in $O_2$ continued for a much longer period and, in fact, during the first 3 weeks of storage its concentration did not drop below 8% (Fig. 1A,D). During the first 4 weeks of storage at 5°C, the $O_2$ concentration in 15-fruit bags was lower (although not always statistically significant) by about 1% than that in the 10-fruit bags (Fig. 1A), whereas during storage at 7°C such differences were not observed (Fig. 1D).

The level of ethylene accumulated within bags stored at 5°C was less with increasing fruit quantity (Fig. 1C). A similar trend was also obtained in bags stored at 7°C, but with ethylene levels almost double those in bags stored at 5°C starting from the third week of storage (Fig. 1F).

The firmness of fruit stored in bags of 30, 40 or 50 $\mu$m thickness was quite similar (Fig. 2), except for fruit stored at 7°C for 7 weeks (Fig. 2C,F,I). The original high firmness of unstored fruit (Fig. 2A,D,G) was maintained in fruit stored in sealed bags containing 10 or 15 fruit kept at 5°C for 5 or 7 weeks (Fig. 2B,E,H), or at 7°C for 5 weeks (Fig. 2C,F,I). The firmness of fruit stored for 7 weeks at 7°C was significantly reduced when sealed in 30 or 40 $\mu$m bags containing 5, 10 or 15 fruit (Fig. 2C,F), except for those stored in 50 $\mu$m bags containing 15 fruit (Fig. 2I). On the other hand, in unwrapped fruit and in those stored in perforated bags, the firmness had already been reduced to a low level after 5 weeks of storage at either temperature (Fig. 2B,C,E,F,H,I). A similar reduction in firmness was also obtained in 5-fruit sealed bags stored at 7°C (Fig. 2C,F,I), whereas in the corresponding 5-fruit bags stored at 5°C, the firmness was maintained at relatively higher levels after 5 weeks (Fig. 2B,E,H).

The CI index of fruit stored in bags of different thickness was similar and, therefore, only data for the 30 $\mu$m bags are presented in Fig. 3. It can be seen that fruit in bags containing 10 or 15 fruit had the lowest CI index at both storage temperatures. On the other hand, unwrapped fruit and fruit stored in perforated bags at 5 or 7°C had high CI indices (above 3.5) except for fruit stored at 7°C for 5 weeks (Fig. 3B). Fruit stored in bags containing five fruit each had an intermediate CI level at both temperatures (Fig. 3A,B).

In the second experiment, commercial-size bags containing 22 fruit (3.2 kg), were examined. In general, the levels of gases accumulated within these bags were similar to those accumulated in bags containing 15 fruit employed in the first experiment, and a similar atmosphere equilibrium was maintained for 9 weeks of storage at both 5 and 7°C (data not shown). In spite of a technical problem that caused a temporary (2 day) increase to 20°C in the 5°C-storage room during the fourth week of storage, no large changes in the bag atmospheres occurred, only a small increase in ethylene concentration (up to 0.8 $\mu$l/l), which lasted for 2 days (data not shown). This suggests that short duration temperature fluctuations may

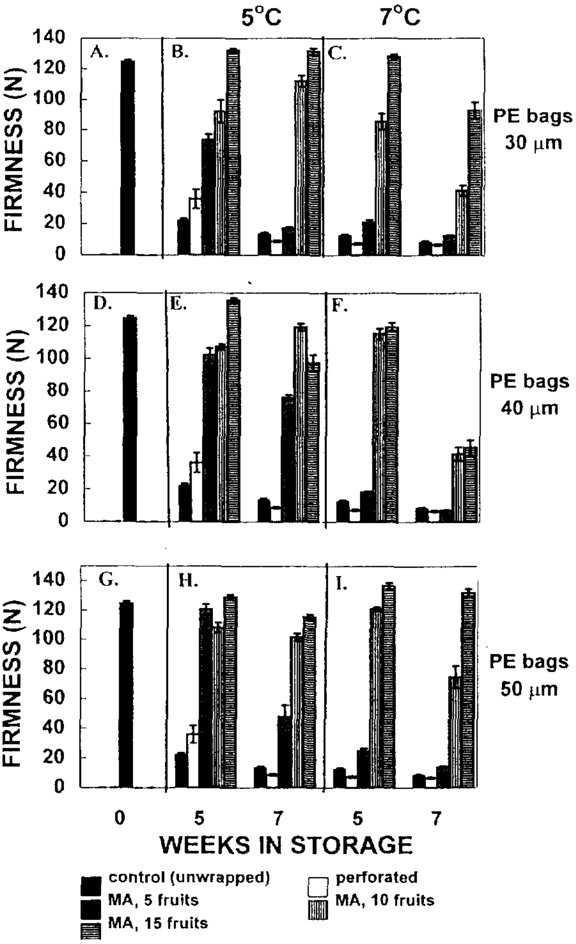

Fig. 2. Effect of storage temperature, bag thickness and number of fruit in the bag on the firmness of 'Hass' avocado fruit immediately after 5 or 7 weeks of storage. Values represent means ± SE of 20 determinations of 10 fruit (Exp. 1).

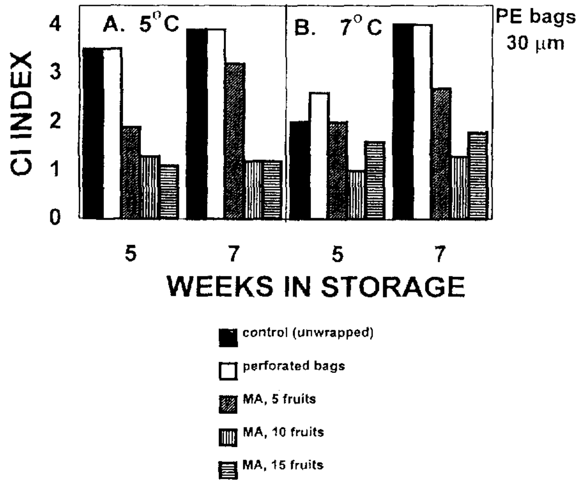

Fig. 3. Effect of storage temperature and fruit quantity in 30 μm bags on CI index in 'Hass' avocado pulp, after 5 or 7 weeks of storage. CI evaluation was done after four additional days of storage under shelf-life conditions (20°C). The values represent weighted averages of 30 fruit in all the treatments, or of 20 fruit in treatments with five fruit per bag. CI index was determined as described in Section 2 (Exp. 1).

not drastically influence the atmosphere equilibrium within the bags.

Fruit stored unwrapped at both 5 and 7°C became soft after 4.5 weeks, whereas fruit sealed in bags remained reasonably firm after 9 weeks of storage at both temperatures (Fig. 4). The softening period (time needed for all fruit to reach firmness ≤ 15 N) after fruit transfer to shelf-life conditions was shortened from 4 days (after up to 6 weeks of MA storage) to 3 days (after 7.5 or 9 weeks of MA storage) (Table 1). After 3 and 4.5 weeks of MA storage the ethylene peak preceded the respiration peak during ripening under shelf-life conditions (Table 2). After 6 weeks of storage both peaks occurred at the same time, while after 7.5 and 9 weeks, the respiration peak preceded that of ethylene production (Table 2). In general, the ethylene production rate at its climacteric peak decreased with increasing MA storage duration. However, the ethylene climacteric peaks of fruit stored in MA were higher than those of unwrapped fruit. On the other hand, the respiration peak of cold-stored fruit was higher than that of unstored fruit, except for fruit stored for 6 or 7.5 weeks, which showed a respiratory peak either lower than, or similar to that of unstored fruit (Table 2).

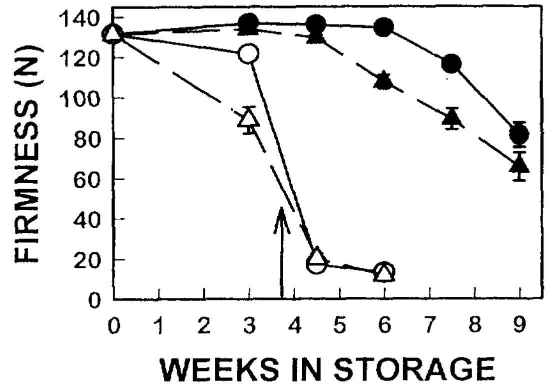

Fig. 4. Effect of storage temperature and MA packaging on firmness of 'Hass' avocado fruit during 9 weeks (Exp. 2). Open symbols represent unwrapped fruit and closed symbols represent fruit stored under MA conditions: ○, ●-storage at 5°C and △, ▲-storage at 7°C. Other details are as described in Fig. 2.

Unwrapped fruit lost about 8% of their original weight during 6 weeks of storage (Fig. 5A), and the subsequent shelf-life softening periods (Fig. 5B). Fruit sealed in plastic bags lost less than 4% of their initial weight during the same period, namely 6 weeks of storage + 4 days in shelf-life (Fig. 5B). This can be compared with the 5.6% weight loss obtained in fruit kept at 20°C right after harvest (0 weeks at storage, Fig. 5B), that became soft 9 days later (Table 1). In contrast to unwrapped treatments, fruit in sealed bags lost only about 1% of their initial weight during 9 weeks of storage (Fig. 5A). MA storage also delayed ripening of 'Hass' avocado fruit, manifested as colour change of the peel, even when the fruit started to soften after 7.5 and 9 weeks of storage at either temperature (Fig. 6). At the final ripening (softening) stage, all treated fruit reached a colour index of 4.5–5.0 (data not shown), similar to that obtained with unwrapped fruit at either temperature (Fig. 6).

When unwrapped fruit was cut after softening, either under shelf-life conditions or in the cold rooms, CI symptoms were observed in the pulp. Unwrapped fruit stored at both cold temperatures, had slight or moderate CI indices after 3 or

Table 1
Effect of storage temperature and duration of MA storage on the number of days required for all 'Hass' avocado fruit to achieve complete softening under shelf-life conditions. Results represent the number of days fruits remained at 20°C until complete softening (firmness ≤ 15 N) (Exp. 2)

| Storage conditions | | Storage period (weeks) | | | | | |
|---|---|---|---|---|---|---|---|
| Packaging | Temperature (°C) | 0 | 3 | 4.5 | 6 | 7.5 | 9 |
| | | Days at 20°C | | | | | |
| Unwrapped | 20 | 9 | — | — | — | — | — |
| Unwrapped | 5 | — | 4 | 1 | 0 | — | — |
| Unwrapped | 7 | — | 3 | 2 | 0 | — | — |
| MA | 5 | — | 4 | 4 | 4 | 3 | 3 |
| MA | 7 | — | 4 | 4 | 4 | 4 | 3 |

4.5 weeks in storage whereas after 6 weeks in storage, fruit had developed moderate and severe CI indices. On the other hand, fruit stored in MA for 9 weeks had a very low CI index at both storage temperatures (Fig. 7). It should be noted that fruit stored under MA at both temperatures had good pulp quality after softening, and all fruit tasted by the panel of specialists were scored as edible, with the typical taste of the 'Hass' cultivar.

## 4. Discussion

This study examines for the first time the possibility of employing the technology of MA packaging for prolonged storage of avocado fruit in a commercial package containing 3.2 kg. Atmospheres containing 2–6% $O_2$ and 3–10% of $CO_2$ have been shown to inhibit softening of avocado fruit and to reduce CI in both CA (Hatton and Reeder, 1972; Barmore and Rouse, 1976; Arpaia et al., 1990; Hatton and Spalding, 1990; Meir et al., 1995) and MA (Scott and Chaplin, 1978; Gonzales et al., 1990) storage systems, at 5 and 7°C. However, gas concentrations in these systems should be monitored carefully, since we have found that Israeli-grown 'Hass' fruit are sensitive to low ( $< 3\%$) oxygen concentrations (Meir et al., 1995). It seems that it is important to reach the desired equilibrium in the bag atmosphere as soon as possible and therefore, bags containing 15 fruit had a slight advantage over those containing 10 fruit. When five fruit were sealed in a bag, the atmosphere composition did not reach sufficiently low oxygen concentrations (Fig. 1A,D) to inhibit ripening (Fig. 2) and prevent pulp discolouration (CI) (Fig. 3). In 10- and 15-fruit bags, the 50 $\mu$m thickness (Fig. 2H,I) resulted in slightly firmer fruit than the 30 $\mu$m thickness (Fig. 2B,C), probably due to the fact that the desired equilibrium was reached faster in these bags (data not shown).

We expected that the modified atmosphere gas composition would be enough to inhibit ripening at both cold temperatures, and in addition to reduce CI at 7°C compared with 5°C storage. In fact, we found just the opposite: fruit stored in bags of 15 at 7°C had more CI (pulp discolouration) (Fig. 3), and except for the 50 $\mu$m bags, these fruit softened faster than the corresponding fruit stored at 5°C (Fig. 2). This could be possibly due to the higher level of ethylene accumulated in bags stored at 7°C compared with bags stored at 5°C (Fig. 1C,F). The negative effect of ethylene accumulated within the package atmosphere, manifested in the aggravation of CI symptoms, has been reported previously (Zauberman and Fuchs, 1973; Lee and Young, 1984). Hence, it may be concluded that the optimal temperature for MA storage of 'Hass' avocado fruit is 5°C rather than 7°C. This temperature was also found to be appropriate for 9-week storage of 'Hass' avocado under CA (Arpaia et al., 1990; Meir et al., 1995).

Although fruit stored under MA remained firm throughout storage, (sometimes maintaining their

Table 2
Effect of storage temperature and MA packaging on respiration and ethylene production rates of 'Hass' avocado fruit during shelf life, following various storage periods

| Storage conditions | | Time to $C_2H_4$ peak (days) | Peak rate of $C_2H_4$ evolution ($\mu$l/kg per h) | Time to $CO_2$ peak (days) | Rate of $CO_2$ evolution (mg/kg per h) |
|---|---|---|---|---|---|
| Packaging | Temperature (°C) | | | | |
| *No storage* | | | | | |
| Unwrapped | 20 | 4.5 ± 0.4 | 160 ± 42 | 5.0 ± 0.0 | 173 ± 13 |
| *After 3 W storage* | | | | | |
| Unwrapped | 5 | 2.0 ± 0.3 | 61 ± 12 | 3.0 ± 0.0 | 275 ± 12 |
| MA | 5 | 2.6 ± 0.2 | 89 ± 4 | 3.4 ± 0.2 | 319 ± 11 |
| Unwrapped | 7 | 2.0 ± 0.0 | 102 ± 13 | 3.0 ± 0.0 | 303 ± 8 |
| MA | 7 | 2.0 ± 0.2 | 108 ± 16 | 3.6 ± 0.2 | 275 ± 33 |
| *After 4.5 W storage* | | | | | |
| Unwrapped | 5 | 2.6 ± 0.4 | 19 ± 2 | 4.0 ± 0.0 | 197 ± 8 |
| MA | 5 | 3.6 ± 0.2 | 44 ± 5 | 4.0 ± 0.0 | 272 ± 18 |
| Unwrapped | 7 | 1.8 ± 0.4 | 22 ± 2 | 4.0 ± 0.0 | 238 ± 8 |
| MA | 7 | 3.6 ± 0.2 | 33 ± 5 | 4.0 ± 0.0 | 251 ± 24 |
| *After 6 W storage* | | | | | |
| Unwrapped | 5 | 1.2 ± 0.2 | 30 ± 5 | 1.0 ± 0.0 | 171 ± 4 |
| MA | 5 | 2.6 ± 0.2 | 41 ± 3 | 2.6 ± 0.2 | 129 ± 8 |
| Unwrapped | 7 | 1.0 ± 0.0 | 28 ± 2 | 1.0 ± 0.0 | 129 ± 6 |
| MA | 7 | 2.4 ± 0.2 | 51 ± 9 | 2.8 ± 0.4 | 144 ± 8 |
| *After 7.5 W storage* | | | | | |
| MA | 5 | 2.6 ± 0.4 | 23 ± 4 | 1.0 ± 0.0 | 181 ± 8 |
| MA | 7 | 2.2 ± 0.2 | 40 ± 10 | 1.0 ± 0.0 | 162 ± 10 |
| *After 9 W storage* | | | | | |
| MA | 5 | 2.4 ± 0.2 | 26 ± 2 | 2.0 ± 0.0 | 230 ± 17 |
| MA | 7 | 2.6 ± 0.2 | 23 ± 2 | 2.0 ± 0.0 | 210 ± 7 |

Results represent the rates of $CO_2$ and ethylene production during their respective climacteric peaks, as well as the number of days fruit remained at 20°C until reaching these peaks. The values are expressed as means of five fruit ± S.E. (Exp. 2).

initial firmness values; Figs. 2 and 4), a sharp decline in shelf life was observed following storage due to rapid softening (Table 1). A similar phenomenon has been reported for 'Hass' avocado fruit stored under CA (Arpaia et al., 1990; Meir et al., 1995), and in air (Zauberman et al., 1977; Cutting and Wolstenholme, 1992). These results indicate that several physiological modifications, leading to rapid fruit ripening following storage, do occur during MA storage, although fruit firmness does not decrease during 7 weeks. This assumption is further supported by the evidence showing that the duration of MA storage is negatively correlated with the time required to reach the ethylene and respiration climacteric peaks during shelf life following storage (Table 2). In addition, a significant decline in the ethylene peak was obtained following prolonged MA storage (Table 2). These two phenomena occurred more rapidly in fruit stored in air than in fruit stored under MA. Most reports show that the ethylene climacteric peak precedes or coincides with the respiration peak (Biale and Young, 1971). However, our results show that the respiratory peak preceded the ethylene peak in 'Hass' avocado fruit stored for 7.5 or 9 weeks under MA (Table 2). This may stem from the fact that the fruit after 7.5 weeks of MA storage were already in their postclimacteric stage of ripening, and the ethylene peak observed represents a response to their transfer from the low storage temperatures (5 or 7°C) to the shelf life temperature (20°C). Furthermore, control fruit stored unwrapped for 6 weeks at either 5 or 7°C, were already soft and ripened (Fig. 4), and therefore their ethylene peak obtained following one day at shelf life (Table 2) also represents a response to the temperature shift rather than exhibiting a real climacteric peak. This may also explain the marked reduction in the magnitude of the ethylene peaks obtained in stored fruit compared with unstored ones (Table 2).

An additional advantage of MA storage is the significant reduction in fruit weight loss (only 1% after 9 weeks) during storage and ripening under shelf-life conditions (Fig. 5). In addition to the economic advantage of weight-loss reduction, this feature also has a physiological benefit in delaying ripening. As reported previously, water stress caused by prolonged storage can result in increased and early ethylene production, which in turn may enhance ripening processes (Littmann, 1972; Adato and Gazit, 1974; Joyce and Shorter, 1992). Our study demonstrates that the high humidity obtained within the PE packages significantly delayed fruit water loss, leading to inhibition of ripening in addition to the ripening-retarding effect of the gas composition created within the bag. On the other hand, the fact that fruit shelf life was significantly shortened following

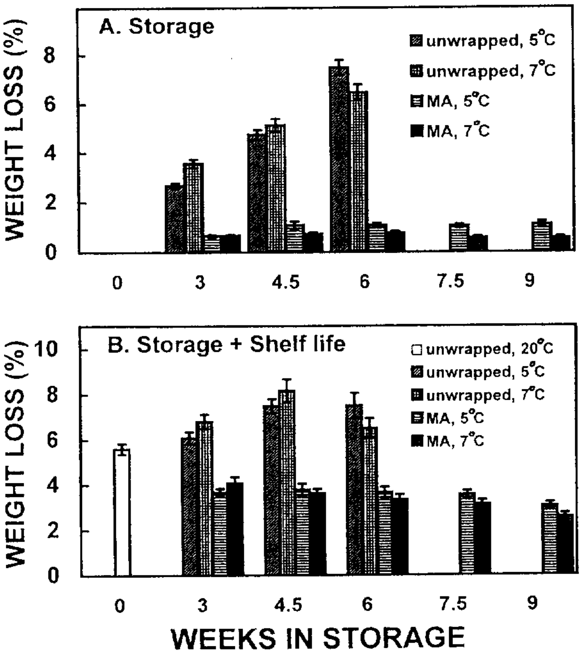

Fig. 5. Effect of storage temperature and MA packaging on weight loss of 'Hass' avocado fruit during cold storage (A) and until complete softening under shelf-life conditions (20°C) was achieved (B) (Exp. 2). Complete softening is defined as described in Table 1.

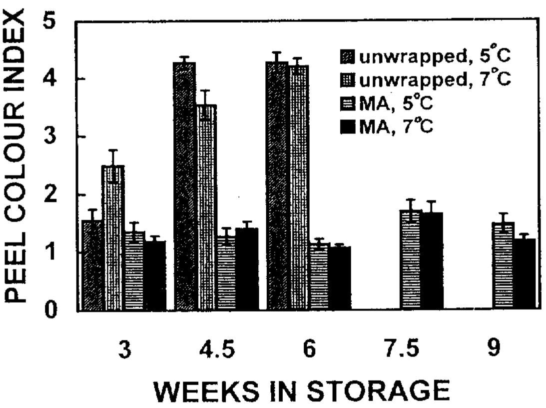

Fig. 6. Effect of storage temperature and MA packaging on fruit ripening index based on colour changes in 'Hass' avocado fruit peel during 9 weeks of storage. Measurements were performed immediately after storage. Values represent means ± SE of three replicates of weighted average of 15 fruit each (Exp. 2).

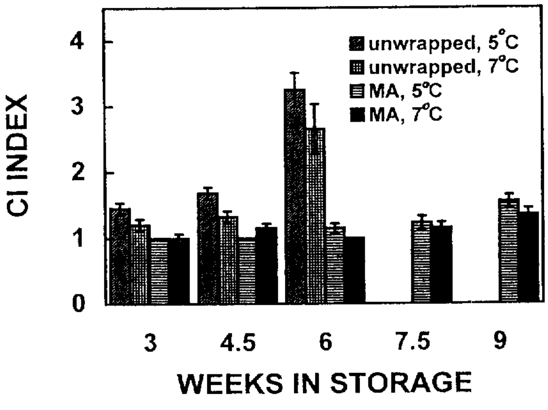

Fig. 7. Effect of storage temperature and MA on CI index in 'Hass' avocado pulp during 9 weeks of storage. Values represent means ± SE of three replicates of weighted averages of 15 fruit each. CI index was determined as described in Section 2, when all fruit of each specific treatment were soft (firmness ≤ 15 N) (Exp. 2).

MA storage, although fruit did not lose weight, indicates that reduced shelf life cannot be ascribed solely to water stress, as suggested previously (Bower and Cutting, 1988; Cutting and Wolstenholme, 1992).

In the present study of avocado MA storage, we have shown that the gas atmosphere composition inhibited ripening (expressed as peel colour changes) during 9 weeks of storage (Fig. 6), although fruit softening had already started, as indicated by the 30% reduction in fruit firmness obtained during this period (Fig. 4). These results imply that MA may have a differential effect on ripening of 'Hass' avocado peel and pulp, as suggested previously for 'Hass' avocado stored under CA (Meir et al., 1995).

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