

# The effect of relative humidity and ethylene scrubbing on 'Fuerte' and 'Hass' avocado fruit quality

M Huysamer and L Maré

Department of Horticultural Science, University of Stellenbosch,  
Private Bag X1, Matieland 7602, South Africa

## Abstract

Throughout the industry the handling technologies for avocados are constantly being evaluated and adapted so as to meet the changing demands of the export market for high quality fruit. In laboratory-scale trials, 'Fuerte' and 'Hass' avocados were stored at non-chilling temperatures (5.5°C and 7°C, respectively) and chilling temperatures (3°C and 5°C, respectively), both in combination with a high (100%) and a low (75%) relative humidity for 28 days. Thereafter, the fruit were ripened in air at 20°C before evaluation. Once eating ripe no more than 44% of the fruit within a treatment for either of the cultivars was sound. The fruit were mostly affected by the internal disorders, grey pulp and vascular browning, while the 'Hass' avocados also had prominent levels of decay. Although previous research has shown that high RH can restrict chilling injury and extend shelf life of avocados, this was not apparent in our work. In a second, semi-commercial trial, 'Fuerte' and 'Hass' avocados were exported from South Africa to France in 20 m controlled atmosphere (CA) integral reefer containers. Potassium permanganate scrubbers used commercially by the industry, were removed from one container to test the effect of ethylene scrubbing on fruit ripening and quality. During the voyage, ethylene levels in both control and scrubberless containers remained very low. Fruit quality on arrival and after ripening showed no differences between the scrubbed and non-scrubbed containers. It was concluded that scrubbers may be unnecessary when shipping fruit under the CA conditions used in this trial.

## INTRODUCTION

Avocados exported from South Africa are more often than not in transit for no fewer than 30 days from the time of harvest. Due to the adverse conditions to which the fruit are exposed by being in cold storage for extended periods, it is not unusual for the fruit to arrive at the market at the incorrect ripeness. With these extended storage periods chilling injury also poses a very real problem for avocado storage (Couey, 1982) and it is for this reason that very low temperature storage is not acceptable. However, higher rela-

tive humidity (RH) levels (95%+) during storage have been proven to restrict chilling injury (Chien *et al.*, 1998) and ripening of different fruit (Adato and Gazit, 1974; Pesis *et al.*, 2000; Xue *et al.*, 1996).

Relative humidity is an environmental factor which influences the rate of water loss of whole plants or excised plant organs (Forney and Brandl, 1992). Physiological processes such as cell expansion, growth, photosynthesis and senescence are affected by this water loss (Forney and Brandl, 1992). The difficulty in controlling and measuring RH has meant

that it is an inconvenience and its role in the physiology of plants has generally been ignored (Gaffney, 1978). Salt solutions have previously been shown to be very effective in controlling humidity but according to Solomon (as reported by Forney and Brandl, 1992) the problem is that a different salt solution is needed for different humidity levels. This, coupled with the fact that RH varies with temperature changes (Forney and Brandl, 1992), poses more of a problem than an inconvenience. Equilibrium RH can also be formed with nonsaturated solutions such as glycerol (Forney and Brandl, 1992). Glycerol solutions are easy to mix, the exact composition for a specific RH can be determined and it is relatively inexpensive (Forney and Brandl, 1992).

It must be remembered that increased RH may have a positive influence on delaying fruit and vegetable ripening, but if the moisture content of the air reaches saturation level (100% RH) it could provide an ideal environment for decay organisms to develop. For this reason Hardenburg *et al.* (1986) recommend RH between 85% and 95% for storage of fresh produce, which presents a balance between microbial spoilage and weight loss (Shirazi and Cameron, 1992). We hypothesised that storage of 'Fuerte' and 'Hass' avocados at high RH levels will allow fruit to be stored at lower than normal temperatures without causing chilling injury symptoms, and will therefore delay fruit ripening.

Ethylene has been shown to be a catalyst for fruit ripening, with avocado being a classic example. The South African avocado industry makes extensive use of controlled atmosphere (CA) shipping to retard fruit softening, and ethylene scrubbers are generally included in the containers despite the fact that atmospheres are not conducive to ethylene biosynthesis and action. For this reason, we hypothesised that removal of the scrubbers would not have a detrimental effect on fruit ripening and quality.

## **MATERIALS AND METHODS**

### ***TRIAL 1: RELATIVE HUMIDITY***

*Experimental set up:* 'Fuerte' and 'Hass' avocado fruit were harvested on the 12<sup>th</sup> of June 2002 and transported at 5.5°C and 7°C, respectively, to the University of Stellenbosch by Westfalia exporters. Fruit size was count 14 (266 – 305 g) and was intended for the export market.

The fruit were sorted on the 21<sup>st</sup> June 2002 and all damaged fruit were discarded. The fruit were stored at the recommended temperature for that stage of the season and at a chilling temperature in combination with two different RH levels for four weeks. The different treatments were: low temperature and high RH (LT-HRH) ('Fuerte' at 3°C, 'Hass' at 5.5°C and 100% RH), high temperature and high RH (HT-HRH) ('Fuerte' at 5.5°C, 'Hass' at 7°C and 100% RH), low temperature and low RH (LT-LRH) ('Fuerte' at 3°C, 'Hass' at 5.5°C and 75% RH) and high temperature and low RH (HT-LRH) ('Fuerte' at 5.5°C, 'Hass' at 7°C and 75% RH). Fruit were placed in 5 L buckets and connected to humidified air supplied via flow boards. Flow rates were about 450 ml.min<sup>-1</sup> during storage. Thereafter, fruit were ripened at 20°C in air to simulate a shelf life period.

The experimental design was a randomised block with four treatments each consisting of six replications with five fruit each.

A representative set of 20 fruit was taken initially and evaluated for firmness prior to the fruit being treated. During the shelf life period the fruit were removed for disorder evaluation as they reached the eating ripe stage. This was assessed by gently squeezing the fruit by hand.

### ***Maturity indices***

*Firmness.* Readings were taken on opposite sides of the peeled fruit with a penetrometer (Southtrade fruit pressure tester, FT 327, Alphonsine, Italy) fitted with a 5 mm tip.

*Moisture content.* Moisture content was

measured only initially when the fruit arrived. It was only done once as moisture content does not change much during the storage period and is used as a maturity index for harvest. Moisture content was determined by the method described by Swarts (1978). The fruit was cut in half and the pip removed. The fruit was grated at the cut surface and weighed. The sample was placed in a microwave on high for two minutes after which it was reweighed. The sample was replaced in the microwave for a further two minutes and reweighed, and the process repeated until a constant mass was achieved. The difference between the initial mass of the sample and the final mass of the sample as a percentage of the initial mass of the sample gave the moisture content of the fruit. This was done on three fruit. For each new two minute cycle a beaker of cold water was placed in the microwave with the fruit sample, to prevent burning of the sample.

*Disorders.* Fruit were evaluated when eating ripe during the shelf life period. Fruit were rated for external disorders: chilling injury, black cold, *Dothiorella* / *Colletotrichum* complex (D/C) and lenticel damage. The fruit were then cut in half and allowed to stand for 10 minutes so any internal disorders could become visible. The fruit were rated for internal disorders: pulp spot, grey pulp and vascular browning. The decay which was rated was: stem-end rot, internal anthracnose and external anthracnose. The statistics for the disorders was calculated as a percentage of the total number of fruit per replication evaluated for disorders.

*Ripening rates.* As the fruit were removed from the shelf life period, the number of fruit per treatment and days at 20°C until ripe were recorded.

*Statistical Analysis.* Analysis of variance (ANOVA) of the main effects and LSD values with a significance level of 5% were obtained using Statistical Analysis Systems (SAS). Pre-

sented data points are the means of the four replications  $\pm$ SE.

#### *TRIAL 2: ETHYLENE SCRUBBING*

*Experimental setup:* Commercially packed 'Fuerte' and 'Hass' fruit were transported from Tzaneen to Cape Town, and containerised on 14<sup>th</sup> June 2002. Fourteen pallets of 'Hass' and six pallets of 'Fuerte' were loaded into each of two 20 m integral CA reefer containers. The potassium permanganate scrubbers normally fitted to the return air duct were removed from one container. Subsequently, a controlled atmosphere of 4% O<sub>2</sub> and 6% CO<sub>2</sub> was established in the containers, and fruit were shipped under a step-down temperature regime of 6°/5.5°/5°C.

*Measurements:* During the two-week voyage, ethylene concentration inside the containers was monitored daily by drawing an air sample through the sampling port with a hand pump and passing it over the sensor of a Dräger Pac III gas monitor. The limit of detection was 0.5  $\mu\text{L.L}^{-1}$  (ppm). In addition, the O<sub>2</sub> and CO<sub>2</sub> concentrations were noted off the electronic data recorder. Upon arrival in Paris, sample cartons of both cultivars were drawn from both containers. An arrival evaluation was performed immediately, including fruit firmness (by hand), lenticel damage, black cold injury, brown cold injury, dusky cold (only for 'Fuerte'), anthracnose and stem-end rot. This was followed by a second evaluation once fruit had ripened at room temperature, including days to ripen, lenticel damage (only 'Fuerte'), black cold injury (only 'Fuerte'), brown cold injury (only 'Fuerte'), dusky cold (only 'Fuerte'), anthracnose, stem-end rot, and the internal defects of pulp spot, grey pulp and vascular browning.

*Statistical analysis:* Due to the semi-commercial nature of the trial, no statistical analysis could be completed. Results are the means of the evaluations.

## RESULTS

### TRIAL 1: RELATIVE HUMIDITY

#### 'Fuerte'

At the start of the experiment the fruit had a mean moisture content of 67.0% and were therefore stored at 5.5°C (Hardy *et al.*, undated). On arrival the fruit had a mean firmness of 10.6 kg.

**Disorders.** There was no significant difference between treatments in the percentage of sound fruit and values ranged between 16.7% – 43.3% with the fruit stored under LT-LRH having the highest percentage (Table 1). The external disorders which occurred were chilling injury and lenticel damage. There were no significant differences between the treatments for lenticel damage (Table 1). The fruit stored under LT had significantly higher chilling injury (21.7%) than the fruit stored

under HT (2.8%) (Table 2).

There were no significant differences between treatments in the percentage pulp spot and its occurrence was no higher than 4.3% within a treatment (Table 1). The fruit stored under HT-LRH had the significantly highest occurrence of vascular browning (60.0%) and there were no significant differences between the remaining treatments (Table 1). The fruit stored under LT had significantly higher grey pulp (50.1%) than the fruit stored under HT (25.0%) (Table 2). Similarly the fruit stored under HRH had significantly higher grey pulp (50.0%) than the fruit stored under LHR (25.0%) (Table 3). Stem-end rot and external anthracnose were less prominent and the highest occurrence was 13.3% external anthracnose (Table 1) but there was a significantly higher occurrence of internal anthracnose in the fruit stored under LT (6.7%) than the fruit stored under HT (0.3%) (Table 2).

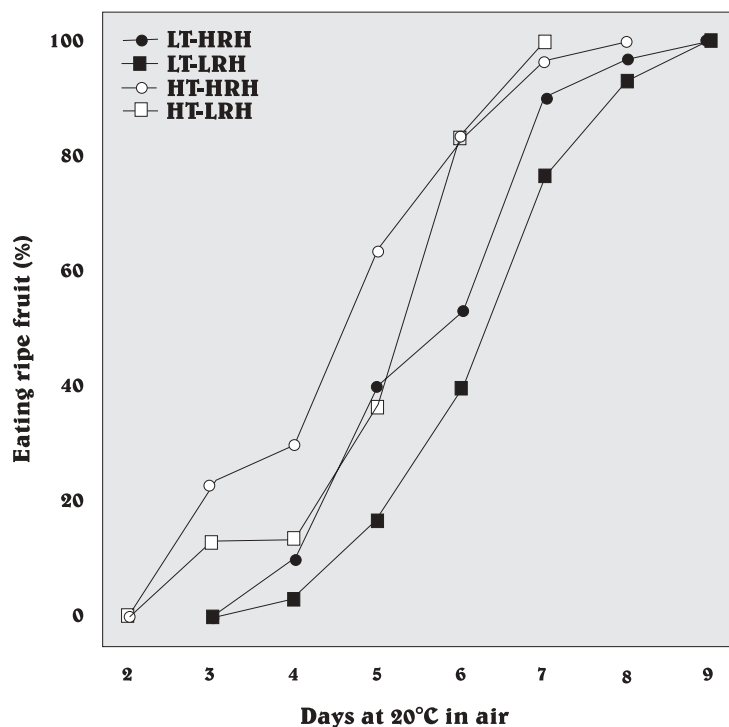
**Ripening rates.** The fruit stored at 3°C (LT) generally had a slower ripening pattern than the fruit stored at 5.5°C (HT) (Fig. 1). At both temperatures the fruit stored under 75% RH ripened slower than those fruit stored under 100% RH.

#### 'Hass'

At the start of the experiment the fruit had a mean moisture content of 77.0% and were therefore stored at 7°C (Hardy *et al.*, undated). On arrival the fruit had a mean firmness of 12.1 kg.

**Disorders.** The percentage sound fruit was no higher than 26.7% for any of the treatments and there was no significant difference between treatments (Table 4). Chilling injury was the only external disorder which occurred, and at levels lower than 5% with no significant differences between treatments (Table 4).

The occurrence of grey pulp was significantly higher in the fruit stored under LT (33.3%) than the fruit stored under HT



**Figure 1. Ripening rates of 'Fuerte' avocado fruit stored at the commercial storage temperature of 5.5°C (HT) or a chilling temperature of 3°C (LT) in combination with either 100% (HRH) or 75% (LRH) relative humidity for 28 days. Fruit were ripened at 20°C in air until eating ripe.**

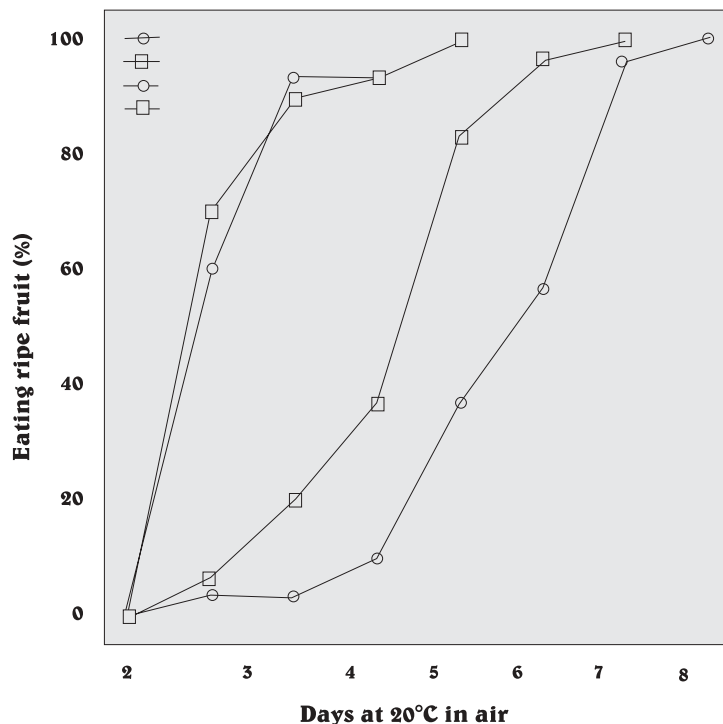
(13.3%) (Table 2). There was no significant difference in the occurrence of vascular browning but levels as high as 50% did occur (Table 4).

The fruit stored under HT-LRH had the highest level of external anthracnose (30.0%) but only significantly higher than the fruit stored under LT-LRH (Table 4). The fruit stored under LT had the significantly highest levels of stem-end rot (21.7%) and internal anthracnose (18.3%) (Table 2). Similarly the fruit stored under HRH had the significantly highest levels of stem-end rot (22.2%) (Table 3).

**Ripening rates.** The fruit stored at 5.5°C (LT) had a distinctly slower ripening pattern than the fruit stored at 7°C (HT) (Fig. 2). Of the fruit stored at 5.5°C, those stored under 100% RH (HRH) ripened slower than those fruit stored under 75% RH (LRH).

#### TRIAL 2: ETHYLENE SCRUBBING

**Ethylene concentrations:** During the 14 day voyage from South Africa to France, ethylene levels were below detectable



**Figure 2. Ripening rates of 'Hass' avocado fruit stored at the commercial storage temperature of 7°C (HT) or a chilling temperature of 5.5°C (LT) in combination with either 100% (HRH) or 75% (LRH) relative humidity for 28 days. Fruit were ripened at 20°C in air until eating ripe.**

**Table 1. Internal and external disorders and the significance levels of temperature and relative humidity of 'Fuerte' avocado fruit stored at 5.5°C (HT) or a chilling temperature of 3°C (LT) in combination with either 100% (HRH) or 75% (LRH) relative humidity for 28 days. Fruit were ripened at 20°C in air until eating ripe prior to evaluation.**

	Sound fruit (%)	Lenticel damage (%)	Pulp spot (%)	Vascular browning (%)	Stem-end rot (%)	External anthracnose (%)
LT-HRH	40.0 ns <sup>z</sup>	3.3 ns	0.0 ns	6.7 b	0.0 ns	6.7 ns
LT-LRH	43.3	3.3	0.0	13.3 b	3.3	0.0
HT-HRH	33.3	0.0	4.3	20.0 b	10.5	0.0
HT-LRH	16.7	0.0	0.3	60.0 a	3.0	13.3
LSD	29.988	6.9532	4.685	15.856	11.034	13.906
Temperature	0.1167	0.1727	0.1573	0.0001	0.1893	0.4877
Humidity	0.5194	1.0000	0.2224	0.0003	0.5837	0.4877
Temp*RH	0.3370	1.0000	0.2224	0.0056	0.1631	0.0466

<sup>z</sup> Means separation within columns using least significant difference (0.05)

**Table 2. Significance levels as influenced by temperature of 'Fuerte' and 'Hass' avocado fruit stored at the commercial storage temperature ('Fuerte': 5.5°C; 'Hass': 7°C) (HT) or a chilling temperature ('Fuerte': 3°C; 'Hass': 5.5°C) (LT) in combination with either 100% (HRH) or 75% (LRH) relative humidity for 28 days. Fruit were ripened at 20°C in air until eating ripe prior to evaluation.**

	'Fuerte'			'Hass'		
	Chilling injury (%)	Grey pulp (%)	Internal anthracnose (%)	Grey pulp (%)	Stem-end rot (%)	Internal anthracnose (%)
LT	21.7 a <sup>2</sup>	50.1 a	6.7 a	33.3 a	21.7 a	18.3 a
HT	2.8 b	25.0 b	0.3 b	13.3 b	6.7 b	2.8 b
LSD	15.986	20.092	6.2347	18.132	12.089	10.526

<sup>2</sup>Means separation within columns using least significant difference (0.05)

limits in both containers, apart from a reading of 0.5 µl.L<sup>-1</sup> in the scrubberless container on day two after departure (data not shown).

**CA conditions and temperature:** The temperatures in both containers were close to ideal, with delivery air temperatures (DAT) following the set points and return air temperatures (RAT) consistently approximately 1°C higher than DAT. The scrubberless reefer maintained CA conditions very close to the set points, but the reefer containing the scrubber showed some fluctuation in both oxygen

and carbon dioxide levels (data not shown).

**Fruit quality:** Fruit of both 'Fuerte' and 'Hass' were rated as 100% 'hard to very hard' upon arrival, with virtually zero quality defects and no detectable differences between fruit from scrubbed and scrubberless containers. Similarly, there were no significant quality defects in the ripened fruit. 'Fuerte' fruit ripened in 6.5 days (minus scrubber) or 4.3 days (with scrubber), whereas 'Hass' took 8.9 days (minus scrubber) or 8.6 days (with scrubber) to attain the eating ripe stage (data not shown).

**Table 3. Significance levels as influenced by relative humidity of 'Fuerte' and 'Hass' avocado fruit stored at the commercial storage temperature ('Fuerte': 5.5°C; 'Hass': 7°C) (HT) or a chilling temperature ('Fuerte': 3°C; 'Hass': 5.5°C) (LT) in combination with either 100% (HRH) or 75% (LRH) relative humidity for 28 days. Fruit were ripened at 20°C in air until eating ripe prior to evaluation.**

	'Fuerte'	'Hass'
	Grey pulp (%)	Stem-end rot (%)
HRH	50.0 a <sup>2</sup>	22.2 a
LRH	25.0 b	6.2 b
LSD	20.092	12.089

<sup>2</sup>Means separation within columns using least significant difference (0.05)

## DISCUSSION

### TRIAL 1: RELATIVE HUMIDITY

**Disorders.** None of the parameters significantly affected the percentage sound 'Fuerte' fruit (Table 1). Temperature did, however, significantly affect the level of chilling injury and thus the fruit stored at the lower temperature were more damaged (Table 2). 'Fuerte' avocados, which are known to be susceptible to pulp spot, were hardly affected by the disorder. In contrast to that, grey pulp was far more prominent and was significantly influenced by both higher RH levels and lower temperatures (Tables 2 and 3). There was a significant interaction between temperature and RH for the occurrence of vascular browning, thus the main effects cannot be discussed (Table 1).

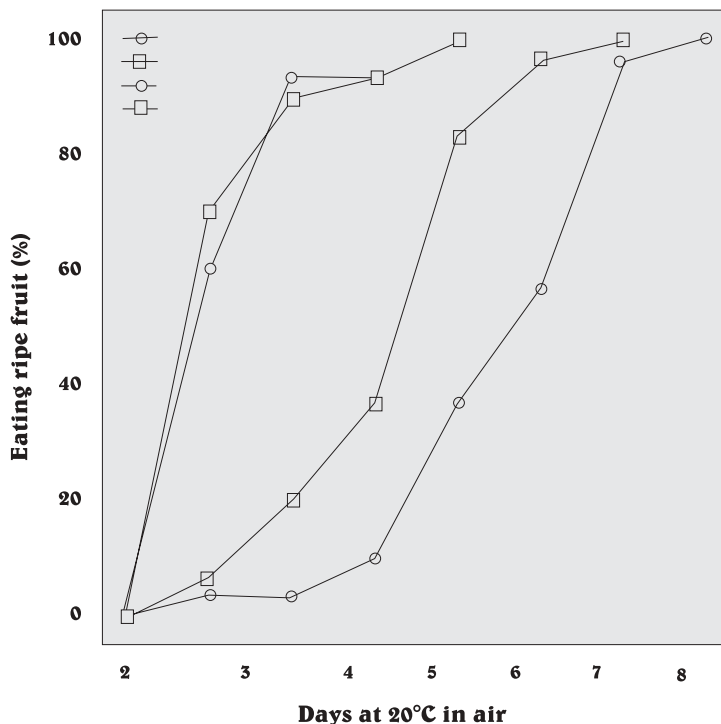
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**Ripening rates.** The fruit stored at 5.5°C (LT) had a distinctly slower ripening pattern than the fruit stored at 7°C (HT) (Fig. 2). Of the fruit stored at 5.5°C, those stored under 100% RH (HRH) ripened slower than those fruit stored under 75% RH (LRH).

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**Figure 2. Ripening rates of 'Hass' avocado fruit stored at the commercial storage temperature of 7°C (HT) or a chilling temperature of 5.5°C (LT) in combination with either 100% (HRH) or 75% (LRH) relative humidity for 28 days. Fruit were ripened at 20°C in air until eating ripe.**

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organisms. Rodov *et al.* (1995) found that the RH within a package could be decreased with sodium chloride, a hygroscopic material, to between 88% to 97% depending on the amount used and the weight of the fruit in the package. This treatment was able to reduce the level of decay during 'red bell' pepper storage and thus extend the shelf life.

**Ripening rates.** For both the 'Fuerte' and 'Hass' experiments temperature had the primary influence as the lower temperature delayed fruit ripening (Figure 1 and 2). However, in 'Fuerte' the ripening was delayed by storage at 75% RH whereas the ripening of 'Hass' was delayed by storage at 100% RH.

Previous research has shown that at lowered RH the ripening of mangos (Pesis *et al.*, 2000), 'Fuerte' avocados (Adato and Gazit, 1974), 'Hass' avocados (Adato and Gazit, 1974) and 'Giant Cavendish' bananas (Xue *et al.*, 1996) was accelerated. This can be ascribed to increased respiration and ethylene production rates at the lower RH level (Pesis *et al.*, 2000).

#### **TRIAL 2: ETHYLENE SCRUBBING**

**Ethylene concentrations.** The threshold concentration for ethylene action in avocado (cultivar 'Choquette') has been reported to be  $0.1 \mu\text{L.L}^{-1}$  (Reid, 1992). However, this is probably true for ethylene in regular atmosphere under ambient temperatures. Ethylene synthesis is reduced by storage at low temperatures, by storage in oxygen concentrations below 8% and by exposure to carbon dioxide concentrations higher than 2% (Kader, 1992). Elevated carbon dioxide levels are also known to inhibit ethylene action, and it can therefore be assumed that the CA and temperature conditions prevailing in this trial were not conducive to ethylene synthesis and action. It therefore becomes debatable whether ethylene scrubbers are necessary. In this trial the container with the scrubbers had less than optimal CA conditions, as oxygen levels rose to approximately 9% for a period of three

days. Nevertheless, no ethylene was detected in the sampled air, and it can be debated that fruit outturn quality would have been poorer had the scrubbers not been present.

**Fruit quality.** The fact that fruit quality was deemed to be the same in both containers suggests that, at least from a practical, commercial point of view the scrubbers had no effect. This point needs to be investigated further, given the preceding discussion on the failure of the CA system to maintain the desired atmospheres and the possibility that the presence of the scrubbers prevented negative consequences.

#### **CONCLUSION**

The storage of 'Fuerte' and 'Hass' avocados at chilling-inducing temperatures in combination with high RH did not show much promise. Both cultivars were affected primarily by internal disorders and decay. The 'Hass' fruit shelf life was extended by the storage at lower temperature and higher RH but this was outweighed by the poor quality of the fruit.

The current approach of the industry in using a combination of CA and ethylene scrubbers during export shipping can be seen to be a 'belt and braces' approach. The scrubbers effectively fulfil the role of additional insurance against fruit ripening and, hence, softening. It would be premature to recommend that the industry should cease using scrubbers in CA reefers until further data are generated on commercial consignments.

#### **ACKNOWLEDGEMENTS**

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