

# The use of CA storage, CO<sub>2</sub> shock treatments and / or 1-MCP treatments on 'Fuerte' and 'Hass' avocados

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## ABSTRACT

With the increasing consumer demand for top quality avocado fruit, storage and handling technologies are being reconsidered. 'Fuerte' avocados were (a) stored in controlled atmosphere (CA), (b) stored in air (RA), or (c) treated with four carbon dioxide shock treatments over three time periods and stored in RA. 'Hass' avocados were (a) stored in CA, with or without 1-MCP, (b) stored in RA, with or without 1-MCP, or (c) treated with two carbon dioxide shock treatments for 48 hours and stored in RA with or without 1-MCP. After storage, fruit were transferred to 20°C until eating ripe to simulate shelf life. 'Fuerte' stored under RA following CO<sub>2</sub> shock were generally firmer than the RA stored fruit without CO<sub>2</sub> shocks, with CA stored fruit about 3 kg firmer (9.75 kg). 'Hass' treated with CO<sub>2</sub> shock and 1-MCP prior to RA storage, were generally firmer than the RA stored fruit, with CA stored fruit about 2 kg firmer (12.2 kg). 'Hass' stored under CA in combination with 1-MCP had a firmness value of 11.5 kg. 'Fuerte' stored under CA showed a lower incidence of pulp spot (0%) and grey pulp (10.3%), and slightly higher internal and external anthracnose (5.1% and 10.3%, respectively) when compared to the RA treated fruit. The 96 hour CO<sub>2</sub> shock treated 'Fuerte' showed little pulp spot, but had of the highest grey pulp ( $\pm 32\%$ ), stem-end rot ( $\pm 16\%$ ) and vascular browning ( $\pm 45\%$ ). 'Hass' stored in air showed the highest percentage of sound fruit (91.3%) while the 1-MCP treated fruit was 85.0% sound. All fruit showed significant rises in respiration and ethylene production on removal from the storage temperatures to 20°C. Maximum respiration for the 'Fuerte' ranged from 138 – 178 mg CO<sub>2</sub>.kg<sup>-1</sup>.h<sup>-1</sup> while that of 'Hass' ranged between 56 – 90 mg CO<sub>2</sub>.kg<sup>-1</sup>.h<sup>-1</sup>. Fruit stored in CA showed positive results compared to the CO<sub>2</sub> shock treated fruit. However, more work needs to be done using CO<sub>2</sub> shock treatments in combination with 1-MCP.

## INTRODUCTION

With the excessive distances that have to be covered by South African grown avocados to reach export markets, transit time can exceed 30 days (Bower and Cutting, 1988). This very often will result in fruit arriving at the incorrect stage of ripeness. The option of storing avocados at very low temperatures to restrict ripening has long since been discarded due to susceptibility to chilling injury (Couey, 1982). This has opened the door for storage

at higher temperatures of between 5 – 13°C (Kader, 1997) in combination with controlled atmosphere (CA) CO<sub>2</sub> shock levels (CO<sub>2</sub> levels which greatly exceed the initial intercellular concentrations of CO<sub>2</sub> are known as CO<sub>2</sub> shock treatments) or 1-methylcyclopropene. Kader (1997) recommends for storage of avocados O<sub>2</sub> levels between 2 – 5% and CO<sub>2</sub> level between 3 – 10%.

1-MCP was proven by De Wild *et al.* (1999) and Rupasinghe *et al.* (2000) to be a

competitive inhibitor of ethylene at the active binding site thus blocking ethylene action and therefore delaying ripening of the fruit. The binding of 1-MCP to the ethylene receptor is more efficient than ethylene itself, thus 1-MCP treatments are effective in very low dosages in the ppb range (Rupasinghe *et al.*, 2000). It has also been found that treatment with 1-MCP at lower temperatures requires higher concentrations of 1-MCP for the same result (Sisler *et al.*, 1996). For this reason treatments with 1-MCP are generally done at room temperature. The reaction time of 1-MCP is varied. Carnations treated with 1-MCP remained insensitive to ethylene for 12 – 15 days at 24°C (Sisler and Serek, 1997).

It was originally thought that increased CO<sub>2</sub> levels acted in the same way as 1-MCP. De Wild *et al.* (1999) however proved that CO<sub>2</sub> acted more as a non-competitive inhibitor in the preliminary stages of ethylene production resulting in a synergistic effect when the two treatments were combined.

We hypothesise that the storage of 'Fuerte' and 'Hass' avocados at 5.5°C with CA, CO<sub>2</sub> shock levels alone or in combination with 1-MCP will extend shelf life. Firmness and quality of the fruit will also be improved.

## **MATERIAL AND METHODS**

**Experimental set up:** 'Fuerte' avocado fruit were harvested in Tzaneen, South Africa and transported to the University of Stellenbosch by Summerfield exporters (harvest and packaging dates not known). Fruit size ranged between count 10 and count 14 (266 g - 450 g). 'Hass' avocado fruit were harvested from Westfalia estates, South Africa and transported to the University of Stellenbosch by Westfalia exporters (harvest and packaging dates not known). Fruit size was count 16 (236 g – 265 g). All fruit was intended for the local market.

The 'Fuerte' and 'Hass' avocado fruit were immediately sorted on arrival (22 June and 4 September, respectively) and all damaged fruit was discarded. The fruit was stored at 5.5°C for 18 days simulating the commercial shipping period from South Africa. Thereafter the fruit was transferred to 20°C until all fruit was ripe to simulate a shelf life period in air. The different treatments for 'Fuerte' were: regular atmosphere (RA), controlled atmosphere (CA), four different carbon dioxide shock treatments over three time periods: 20% CO<sub>2</sub> for 24 hours, 48 hours and 96 hours; 30% CO<sub>2</sub>

for 24 hours, 48 hours and 96 hours; 40% CO<sub>2</sub> for 24, 48 hours and 96 hours; 50% CO<sub>2</sub> for 24 hours, 48 hours and 96 hours. The different treatments for 'Hass' were: regular atmosphere (RA), controlled atmosphere (CA), two different carbon dioxide shocks treatments: 30% CO<sub>2</sub> for 48 hours (48-S1) and 50% CO<sub>2</sub> for 48 hours (48-S2) as well as three 1-MCP treatments. The fruit were treated for 24 hours at room temperature with 500 ppb before being moved into air (1-MCP), CA (CA 1-MCP) and CO<sub>2</sub> shock of 50% for 48 hours (48-S2 1-MCP) at 5.5°C.

Fruit were placed in 25 L buckets and connected to humidified air supplied via flow boards. Flow rates were about 450 mL.min<sup>-1</sup> during treatment whereafter fruit were held in air for the remainder of the experiment. The atmosphere composition was checked regularly and maintained within 10% of the commercially used Transfresh atmospheres using an O<sub>2</sub>/CO<sub>2</sub> analyser (PBI-Dansensor, Combi Check 9800-1, Ringsted, Denmark). Both experiments were a randomised block design with 'Fuerte' having 14 treatments, each consisting of 3 replications with 25 fruit each and 'Hass' having 9 treatments, each consisting of 4 replications with 30 fruit each.

A representative set of 20 fruit was taken initially and evaluated prior to the fruit being put under atmosphere. Thereafter, 5 fruit per replication were removed for evaluation after 18 days of storage. During the 7 days of shelf life 14 fruit per replication for 'Fuerte' and 20 fruit per replication for 'Hass' were removed for evaluation as they ripened. This was done by gently squeezing the fruit.

### **Maturity indices**

**Firmness.** After 18 days 5 fruit per replication were evaluated. Readings were taken on opposite sides of the 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 (1980). The fruit was cut in half and the pip removed. The flesh was grated at the cut surface and weighed, before drying in an oven at 50°C over night whereafter it was weighed. The sample was replaced

in the oven for a further 4 hours and reweighed and the process repeated until a constant mass was achieved. The percent moisture content of the fruit was calculated as  $100 \text{ (initial mass - final mass) / (initial mass)}$ . This was done on three fruit.

**Disorders.** Fruit was evaluated as the ripe fruit was removed from the shelf life period. Fruit was rated externally for lenticel damage and external anthracnose. The fruit was then cut in half and allowed to stand for 10 minutes so that the disorders could become visible. The fruit was rated for grey pulp, stem-end rot, vascular browning, internal anthracnose, pulp spot, black cold, and *Dothiorella* / *Colletotrichum* complex (D/C). The incidence of disorders was expressed as a percentage of the total number of fruit evaluated for disorders per replication.

**Respiration.** Three fruit (during the 18 days storage) and one fruit (during the 7 days shelf life) were enclosed in 5 L buckets to measure respiration and ethylene production. CO<sub>2</sub> levels were measured with the use of an infrared gas analyser (IRGA) (Infra-Red Gas Analyser, S151, Kingston, Ontario), which was connected to the outflow from each of the buckets. Readings were taken approximately every third day during the storage time and every day during the shelf life period. The measurements on fruit treated with CO<sub>2</sub> shocks, or CA, were taken after the respective treatments were completed and the fruit held in air. This is because the CO<sub>2</sub> shock and controlled atmospheres had CO<sub>2</sub> levels >0.2% which is the upper limit of the IRGA.

**Ethylene production.** Gas samples were taken from the outflow of each bucket (except the CA) every third day during the storage period, and daily for all treatments during the shelf life period. Samples were analysed by gas chromatograph (GC Series 3000, Varian 4290 integrator, Varian Instrument Group, Palo Alto, California).

**Internal Ethylene.** A partial vacuum was applied on individual fruit with the use of a glass vacuum container with a gas tight lid and a vacuum pump (Saltveit, 1982). Within the container the fruit was held in a flask filled with water with a septum at the point where the gas accumulates when the vacuum is applied. After the vacuum had been applied and released, a sample of the extracted gas was taken with a gas tight syringe and evaluated using a gas chromatograph. An initial representative set of 6 fruit were evaluated on the

arrival date. On removal after 17 days storage, 1 fruit per repetition was evaluated, and another fruit per repetition again after 8 days for 'Fuerte' and 6 days for 'Hass' at 20°C.

**Ripening peaks.** As fruit were removed from the shelf life period the number of fruit per treatment and days at 20°C 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). Presented data points are the means of the replications ±SE.

## RESULTS AND DISCUSSION

### Experiment 1: Fuerte

At the start of the experiment the fruit had a mean moisture content of 67.7%. This meant that for the entire duration of the storage time the fruit could be stored at 5.5°C (Hardy *et al.* undated).

### Maturity indices

**Firmness.** After 18 days storage at 5.5°C fruit from five of the treatments were signifi-

**Table 1. Firmness (kg) of 'Fuerte' avocado fruit stored at 5.5°C for 18 days under regular atmosphere (RA), controlled atmosphere (CA) and four carbon dioxide shocks over three time periods: 24 hrs, 48 hrs and 96 hrs. (eg. carbon dioxide shock no. 2 for 48 hours: 48 - S2)**

	Firmness
RA	6.68cd
CA	9.75a
24 - S1	6.84cd
24 - S2	6.17d
24 - S3	7.53bcd
24 - S4	8.35abc
48 - S1	5.79d
48 - S2	9.62a
48 - S3	5.97d
48 - S4	9.97a
96 - S1	9.87a
96 - S2	9.01ab
96 - S3	9.71a
96 - S4	8.60abc
LSD	2.0593

**Table 2. Internal and external disorders (%) of 'Fuerte' avocado fruit stored at 5.5°C for 18 days and at 20°C, until ripe, under regular atmosphere (RA), controlled atmosphere (CA) and four carbon dioxide shocks over three time periods: 24 hrs, 48 hrs and 96 hrs (eg. carbon dioxide shock no. 2 for 48 hours: 48 - S2).**

	Pulp spot	Grey pulp	Stem-end rot	Vascular browning	Anthracnose	
					Internal	External
RA	45.10a	17.65cd	1.96c	7.84e	3.92ab	3.92b
CA	0.00e	10.25d	7.69abc	17.95de	5.13ab	10.25b
24 - S1	25.64b	17.95cd	5.13bc	20.51cde	0.00b	7.69b
24 - S2	25.64b	23.08bcd	5.13bc	33.33abcd	0.00b	5.13b
24 - S3	12.70cd	19.99bcd	5.34bc	27.93bcd	2.56ab	16.85b
24 - S4	7.69de	14.70d	4.44bc	22.39cde	0.00b	7.35b
48 - S1	21.63bc	21.15bcd	9.78abc	28.84bcd	2.08ab	9.29b
48 - S2	4.86de	20.83bcd	4.17c	27.77bcd	5.55a	13.89b
48 - S3	5.13de	33.97bc	2.78c	44.66ab	0.00b	7.69b
48 - S4	0.00e	12.82d	7.69abc	20.15cde	0.00b	12.82b
96 - S1	0.00e	14.65d	14.84abc	39.19abc	4.76ab	17.40b
96 - S2	0.00e	58.97a	20.51a	51.28a	2.56ab	38.46a
96 - S3	2.56de	35.89b	17.95ab	51.28a	2.56ab	17.95b
96 - S4	0.00e	17.95cd	15.38abc	38.46abc	0.00b	20.51ab
<b>LSD</b>	<b>10.464</b>	<b>17.527</b>	<b>13.602</b>	<b>19.152</b>	<b>5.355</b>	<b>18.824</b>

cantly firmest: 48-S4 (10.0 kg), 96-S1 (9.9 kg), CA (9.8 kg), 96-S3 (9.7 kg) and 48-S2 (9.6 kg) (Table 1). The significantly softest fruit were from treatments 48-S1 (5.8 kg) and 48-S3 (6.0 kg). Fruit treated for 24 hours with CO<sub>2</sub> shock had firmness values which ranged from 6.2 kg to 8.4 kg with 24-S4 being the firmest although only significantly firmer than 24-S2. The fruit treated with CO<sub>2</sub> shock for 96 hours showed less variation with firmness values ranging between 8.6 kg and 9.9 kg but no significant difference between the treatments.

Knee (1980) found that apples stored under CA had flesh softening rates half of maximal at 2.5 – 4.0% O<sub>2</sub>. Similar results were found by Bender (1989) in an experiment with 'Gala' apples. Fruit treated with 1.1% O<sub>2</sub> and 3.2% CO<sub>2</sub> had flesh firmness levels >20 N/cm<sup>2</sup> firmer than the control fruit. From Table 1 this is also apparent as the CA treated fruit had firmness levels more than 3 kg firmer than the RA treated fruit.

The extreme levels of CO<sub>2</sub> in the shocks results in a build up of CO<sub>2</sub> within the fruit via diffusion. These increased levels of CO<sub>2</sub> pre-

vent extensive loss of sugars and overripening and thus delaying fruit softening (Salisbury, 1991). In a storage experiment with kiwifruit, fruit were treated with 2, 4 and 6 intermittent exposures to 30% CO<sub>2</sub> stored at 0°C and compared to an air treatment (Nicolas, 1989). In all cases a significant effect in delaying fruit softening was observed and the effect increased with the number of exposures to high CO<sub>2</sub>. Both concentration of CO<sub>2</sub> and length of exposure had an effect on fruit ripening. However the interaction between CO<sub>2</sub> concentration and length of exposure by the fruit to CO<sub>2</sub> shock was also significant (P = 0.0008), and main effects cannot be discussed individually.

**Disorders.** Pulp Spot occurred at low levels in CO<sub>2</sub> shock treated fruit at the longer exposure times (96 hours) but was absent in the CA treated fruit (Table 2). The CO<sub>2</sub> shock treated fruit (24 hours) displayed high levels of pulp spot with RA treated fruit having significantly highest levels (45%).

CA treated fruit displayed the significantly lowest level of grey pulp (10.3%) while 17.7% of the RA treated fruit had grey pulp (Table 2).

**Table 3. Interaction between time and concentration of internal and external disorders of Fuerte avocado fruit stored at 5.5°C for 18 days and at 20°C, until ripe, under four carbon dioxide shocks over three time periods: 24 hrs, 48 hrs and 96 hrs.**

	Pulp spot	Grey pulp	Stem-end rot	Vascular browning	Internal anthracnose	External anthracnose
Time	0.0001	0.0207	0.0027	0.0009	0.3403	0.0135
Concentration	0.0013	0.0023	0.9864	0.0430	0.2793	0.5773
Time*Concentration	0.0205	0.0212	0.9092	0.6733	0.2982	0.3943



The significantly highest level of grey pulp occurred in the 96 – S2 treated fruit. The main effects of CO<sub>2</sub> shock treated fruit cannot be discussed as the two components length of exposure and CO<sub>2</sub> concentration show significant interaction ( $P = 0.0212$ ) (Table 3).

The significantly lowest levels of stem end rot were found in the RA treated fruit (2.0%) while the CA treated fruit had 7.7% of the fruit infected (Table 2). The occurrence of stem-end rot increased with the length of exposure to CO<sub>2</sub> (Table 3) shocks with the significantly highest levels occurring in the 96 – S2 treated fruit (20.5%).

The interaction between length of exposure and CO<sub>2</sub> concentration was not significant for vascular browning (Table 3). As the length of exposure increased the occurrence of vascular browning increased with treatment

**Table 4. Firmness (kg) of ‘Hass’ avocado fruit stored at 5.5°C for 18 days under regular atmosphere (RA), controlled atmosphere (CA) and two carbon dioxide shocks over 48 hrs as well as three relevant 1-MCP treatments (eg. carbon dioxide shock no. 2 for 48 hours: 48 - S2).**

	Firmness
RA	10.1 <sup>b</sup>
1-MCP	10.7 <sup>ab</sup>
CA	12.2 <sup>a</sup>
CA 1-MCP	11.5 <sup>ab</sup>
48-S1	10.1 <sup>b</sup>
48-S2	10.3 <sup>b</sup>
48-S2 1-MCP	11.4 <sup>ab</sup>
LSD	1.6009

**Table 5. Internal and external disorders (%) of ‘Hass’ avocado fruit stored at 5.5°C for 18 days and at 20°C until ripe, under regular atmosphere (RA), controlled atmosphere (CA) and two carbon dioxide shocks for 48 hrs as well three relevant 1-MCP treatments (eg. carbon dioxide shock no. 2 for 48 hours: 48 - S2).**

	Sound	Stem-end rot	Vascular browning	Internal anthracnose
RA	91.30 <sup>a</sup>	3.75 <sup>d</sup>	3.75 <sup>c</sup>	1.25 <sup>e</sup>
1-MCP	85.00 <sup>ab</sup>	5.00 <sup>d</sup>	3.75 <sup>c</sup>	7.50 <sup>de</sup>
CA	71.50 <sup>cd</sup>	20.95 <sup>bc</sup>	5.00 <sup>c</sup>	12.44 <sup>cd</sup>
CA 1-MCP	54.00 <sup>fg</sup>	28.41 <sup>abc</sup>	16.14 <sup>ab</sup>	27.47 <sup>ab</sup>
48-S1	75.00 <sup>bc</sup>	17.50 <sup>c</sup>	6.25 <sup>bc</sup>	11.25 <sup>cde</sup>
48-S2	61.20 <sup>def</sup>	34.26 <sup>a</sup>	3.37 <sup>c</sup>	17.57 <sup>bcd</sup>
48-S2 1-MCP	69.30 <sup>cde</sup>	18.39 <sup>bc</sup>	3.69 <sup>c</sup>	19.70 <sup>bc</sup>
LSD	12.548	12.239	10.389	11.167

96 – S2/S3 displaying the significantly highest levels (51.3%) (Table 2). RA treated fruit displayed the significantly lowest levels (7.8%) with CA treated fruit being 18.0% affected.

With regard to both internal and external anthracnose there were few significant differences between the different treatments (data not shown). The remaining disorders not discussed occurred either at low levels or not at all.

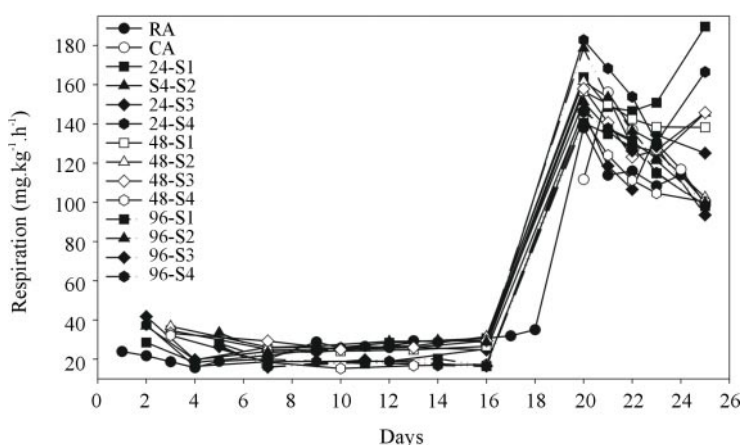
‘Fuerte’ avocados treated with an initial CO<sub>2</sub> concentration of 5% which increased to 35% CO<sub>2</sub> three days after harvest followed by normal storage prevented anthracnose, chilling injury, grey flesh and pulp spot (Truter and Eksteen, 1987). In this study the same CO<sub>2</sub> shock treated fruit showed low levels of pulp spot (Table 2). However, the main effects cannot be discussed as the interaction between length of exposure and CO<sub>2</sub> concentration was significant ( $P = 0.0205$ ) (Table 3).

**Respiration.** Respiration rates of the CO<sub>2</sub> shock treated fruit dropped between 20 – 30 mg CO<sub>2</sub>/kg.h from the first to the second readings (Fig. 1). Thereafter as with the RA treated fruit there was a relatively constant respiration rate while the fruit were held at 5.5°C. With the onset of the shelf life period and increase in temperature to 20°C all the fruit showed a sharp rise in respiration of at least 110 mg CO<sub>2</sub>kg<sup>-1</sup>.h<sup>-1</sup>. The CA treated fruit reached maximum respiration rates a day later than the rest of the treated fruit. In all fruit there was a decline in respiration towards the end of the experiment. The subsequent slight rises were due to decay and overripe fruit.

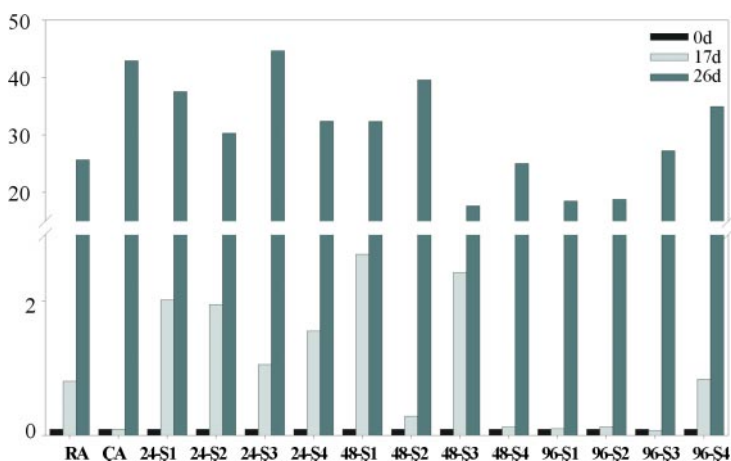
Temperature has the primary influence on the respiration of fruits (Blanke, 1991). A 20°C increase in temperature would result in a 2 –

2.5 fold increase in respiration (Salisbury and Ross, 1991). This would explain the distinct rises in respiration for the all the fruit regardless of treatment on exposure to 20°C during the shelf life period (Fig. 1).

The rise in respiration during ripening of certain fruit was named the respiratory climacteric by Kidd and West (1925). For avocado fruit it is facilitated by detachment from the tree (Blanke, 1991). The use of CA in fruit storage reduces the gradient of CO<sub>2</sub> from the fruit to the ambient atmosphere and therefore causes an accumulation of CO<sub>2</sub> within the fruit (Blanke, 1991), thus slowing respiration.



**Figure 1. Respiration (mg.kg<sup>-1</sup>.h<sup>-1</sup>) of Feurte avocado fruit stored at 5.5°C for 18 days and at 20°C for 7 days under regular atmosphere (RA), controlled atmosphere (CA) and four carbon dioxide shocks for three time periods: 24 hrs, 48 hrs and 96 hrs (eg. carbon dioxide shock no. 2 for 48 hours 48-S2).**



**Figure 2. Internal Ethylene content (ppm) of 'Feurte' avocado fruit stored at 5.5°C for 18 days and at 20°C for 7 days under regular atmosphere (RA), controlled atmosphere (CA) and four carbon dioxide shocks for three time periods: 24 hrs, 48 hrs and 96 hrs (eg. carbon dioxide shock no. 2 for 48 hours 48-S2).**

This further agrees with Young *et al.* (1962), who found that levels of CO<sub>2</sub> between 5% and 10% for 21 days depressed respiration of avocado fruit and delayed the climacteric rise in respiration. The CA treated fruit in this study did not respire any less than the RA treated fruit but did, however, peak a day later.

The CO<sub>2</sub> shock treatments result in a progressive reduction in fruit respiration (Blanke, 1991). It can be seen that the respiratory peaks of all the CO<sub>2</sub> shock treated fruit in this study were not delayed and did not peak lower when compared to the RA treated fruit.

#### **Ethylene production, internal ethylene and ripening peaks.**

Ethylene is a hormone directly involved in fruit ripening (Salisbury & Ross, 1991). This is most evident when comparing the ethylene production, internal ethylene and ripening peaks of the fruit treated with CO<sub>2</sub> shock levels for 96 hours. The ethylene production of these fruit stayed low with the onset of the shelf life period when compared to the other treated fruit. No distinct peak was reached (data not shown). A similar pattern develops for internal ethylene with the same fruit showing lower levels after both 17 days and again after the shelf life period (Fig. 2). This relationship between ethylene and fruit ripening is then displayed in Fig. 3 where the same 96 hour CO<sub>2</sub> shock treated fruit generally had slower fruit ripening and generally also had firmer fruit after the 18 day storage period.

The same pattern is not as clearly seen for the RA and CA treated fruit. After 26 days storage the RA treated fruit had internal ethylene levels approximately 20 ppm less than the CA fruit (Fig. 2). The RA stored fruit, however, ripened three days quicker than the CA fruit (Fig. 3).

#### **Experiment 2: Hass**

At the start of the experiment the fruit had a mean moisture content of 68.3%, and

consequently the fruit was stored at 5.5°C (Hardy *et al.* undated).

### Maturity indices

**Firmness.** On removal from the 18 day storage period at 5.5°C the CA treated fruit were the firmest (12.2 kg), however not significantly firmer than CA 1-MCP (11.5 kg), 48 – S2 1-MCP (11.4 kg) and 1-MCP (10.7 kg) (Table 4). The RA treated fruit were of the significantly softest (10.1 kg).

The prevention of ethylene action by 1-MCP means that 1-MCP treated fruit should be firmer than untreated fruit, as ethylene is

directly involved in fruit softening. This was found by Rupasinghe *et al.* (2000) and Feng *et al.* (2000) after treatment of apples with 1-MCP. This was the case when comparing RA treated fruit and 1-MCP treated fruit in this study. However, the firmness difference was not significant (Table 4).

It was further found by de Wild *et al.* (1999) that the increased CO<sub>2</sub> levels and 1-MCP treatments had a synergistic effect as they act at different points in the ethylene production process. This was not apparent when CA 1-MCP fruit and 1-MCP fruit were compared, as there was no significant difference in firmness (Table 4).

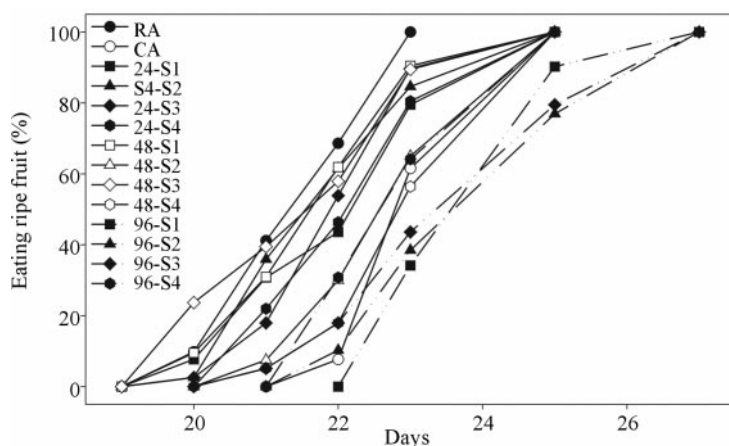
**Disorders.** External anthracnose was not prominent, with three of the treatments having no occurrence of the disorder. The remaining treatments had no significant difference with the highest percentage being 2.5% (data not shown).

Grey pulp occurred in low levels throughout all the treatments with the highest percentage being only 5%. There was no significant difference between any of the treatments (data not shown).

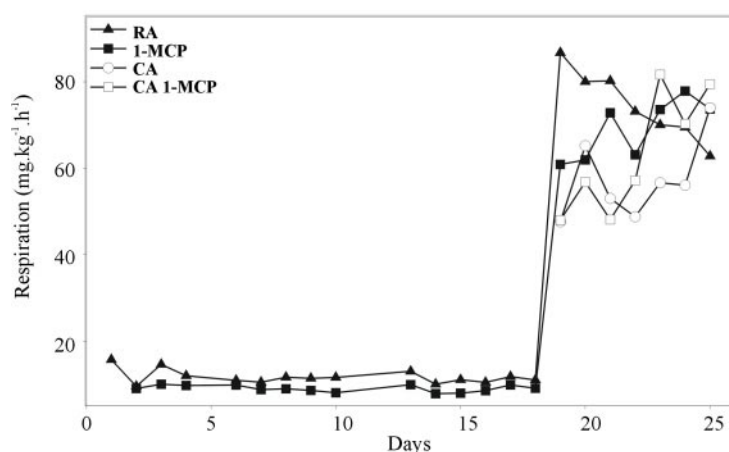
Stem-end rot was the most prominent disorder with 48 – S2 having the significantly highest percentage (34.3%) (Table 5). RA and 1-MCP fruit were the least affected by stem-end rot. CA treated fruit had 21% stem-end rot.

Vascular browning was significantly highest in CA 1-MCP fruit (16.1%) with the next highest being only 6.3% (Table 5). Five of the treatments had the significantly lowest percentage of vascular browning, at 3.6% or lower.

Internal anthracnose was significantly highest in CA 1-MCP (27.5%) and significantly lowest in RA (1.3%) (Table 5). The remaining treatments fell between 10% and 25%. The remaining disorders for which the fruit were evaluated did not occur.



**Figure 3.** Ripening peaks of 'Ferte' avocado fruit stored at 5.5°C for 18 days and at 20°C until ripe under regular atmosphere (RA), controlled atmosphere (CA) and four carbon dioxide shocks for three time periods: 24 hrs, 48 hrs and 96 hrs (eg. carbon dioxide shock no. 2 for 48 hours 48-S2).



**Figure 4.** Respiration (mg.kg<sup>-1</sup>.h<sup>-1</sup>) of 'Hass' avocado fruit stored at 5.5°C for 18 days and at 20°C until eating ripe under regular atmosphere (RA), controlled atmosphere (CA) and two carbon dioxide shocks for 48 hrs (data not shown) and three relevant 1-MCP treatments.

In general 'Hass' avocados are known to be far less susceptible to disorders than some other cultivars. This is most clearly seen as the RA treated fruit had the lowest incidence of each mentioned disorder and further support for this can be seen in Table 5 where the RA treated fruit had the significantly highest percentage of sound fruit (91.3%).

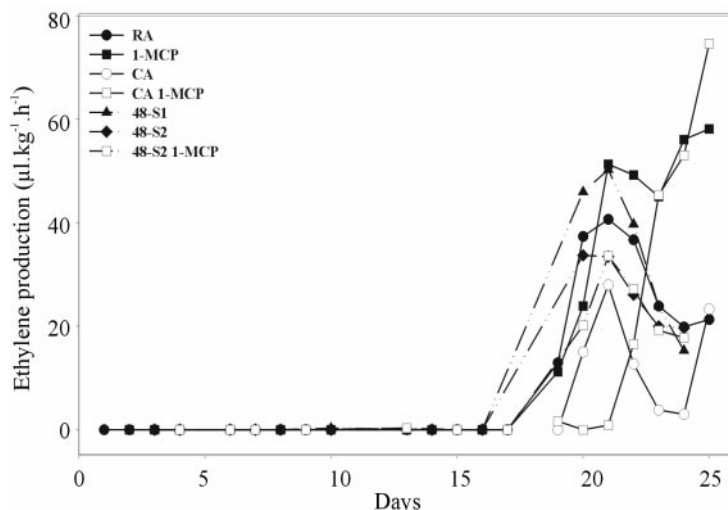
**Respiration.** The CO<sub>2</sub> shock treated fruit had respiration rates which dropped approximately 20 mg CO<sub>2</sub>kg<sup>-1</sup>.h<sup>-1</sup> from the first to the

second readings (Fig. 4). Thereafter, as with the remaining treated fruit, there was a relatively constant respiration rate while the fruit were held at 5.5°C. With the onset of the shelf life period and subsequent increase in temperature to 20°C, all the fruit showed a sharp rise in respiration of at least 60 mg CO<sub>2</sub>kg<sup>-1</sup>.h<sup>-1</sup>. The CA, 1-MCP and CA 1-MCP fruit did not display a distinct peak in respiration as the other treated fruit did with a subsequent drop off in respiration. Thus, they were delayed the most in reaching their maximum respiration levels.

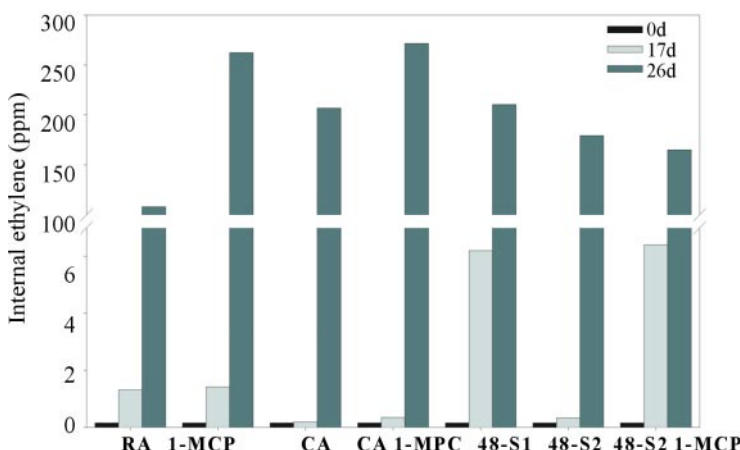
The average respiration rate of pear fruit treated with 1-MCP and held in air for 3 to 5 days was significantly lower than the control (De Wild *et al.*, 1999). In this study this trend was apparent as the fruit were transferred to the shelf life period at 20°C (Fig. 4). However, five days later the trend was reversed possibly as the effects of the 1-MCP wore off, and respiration rates of the 1-MCP treated fruit continued to rise while the RA fruit respired at a slower rate. CA treated fruit had a slightly lower respiration rate than the CA 1-MCP treated fruit over the majority of the shelf life period at 20°C.

**Ethylene production.** Ethylene production was not recorded for any of the treated fruit until the onset of the shelf life period (Fig. 5). As with respiration, most of the treated fruit showed a relatively distinct peak in ethylene production. This was not the case for the 1-MCP and CA 1-MCP treated fruit, which did not reach a turning point before the end of the experiment. CA 1-MCP had the highest recorded level of ethylene production, and 1-MCP second highest on the final day of the experiment. The remaining treatments all peaked four or five days earlier.

According to Kader (1986) elevated CO<sub>2</sub> levels can reduce, promote or have no effect on ethylene production depending on the commodity and CO<sub>2</sub> concentration. Burg and Burg (1967)



**Figure 5.** Ethylene production (µl.kg<sup>-1</sup>.h<sup>-1</sup>) of 'Hass' avocado fruit stored at 5.5°C for 18 days and at 20°C until eating ripe under regular atmosphere (RA), controlled atmosphere (CA) and two carbon dioxide shocks for 48 hrs (eg. carbon dioxide shock no. 2 for 48 hours : 48-S2) and three relevant 1-MCP treatments.



**Figure 6.** Internal ethylene (ppm) of 'Hass' avocado fruit stored at 5.5°C for 18 days and at 20°C until eating ripe under regular atmosphere (RA), controlled atmosphere (CA) and two carbon dioxide shocks for 48 hrs (eg. carbon dioxide shock no. 2 for 48 hours : 48-S2) and three relevant 1-MCP treatments.



also demonstrated that  $O_2$  is needed for the production and action of ethylene. From Fig. 5 a similar trend can be observed as the ethylene production levels of the CA treated fruit were far lower than the RA fruit with the onset of the shelf life period. From that point as the ethylene production rate of the RA fruit decreased, that of the CA fruit continued to rise without reaching a maximum before the end of the experiment, possibly as the effects of the CA wore off.

Untreated Gulfruby plums and Beauty plums show a typical climacteric. However, when treated with 1-MCP, ripening and ethylene production were delayed for several days (Abdi *et al.*, 1997). This was also apparent in the suppressed-climacteric phenotype: Shiro plums and Rubyred plums. Similar results were found on 'Hass' avocados treated with 1-MCP: subsequent treatment with ethylene had no effect and the peak in ethylene production was delayed by 12 to 13 days when stored at 22°C (Feng *et al.*, 2000). The results were the same when pears were treated with 1-MCP (de Wild *et al.*, 1999). There was a significant drop in ethylene production compared to the control when averaged between three and five days. Very similar results were found in this study (Fig. 5) where the ethylene production of 1-MCP treated fruit was delayed by at least four days when compared to the RA treated fruit.

De Wild *et al.* (1999) found a combined effect of treatment with CA and 1-MCP on pears. The ethylene production was significantly less in the combined treatment than in CA and 1-

MCP alone. When considering Fig. 5, the CA treated fruit reached a peak and tapered off while the 1-MCP treated fruit did not reach a distinct ethylene peak before the end of the experiment. The CA 1-MCP treated fruit also continued to increase ethylene production until termination of the experiment. Furthermore the increase in ethylene production started two days later than in any of the other treated fruit.

**Internal ethylene.** Internal ethylene content (IEC) showed large variation (Fig. 6). After 17 days storage at 5.5°C the significantly lowest IEC was found in CA treated fruit (0.2 ppm). After shelf life at 20°C the significantly highest IEC was found in 1-MCP and CA 1-MCP treated fruit, while the significantly lowest was found in the RA treated fruit.

**Ripening peaks.** Results were similar to that of Feng *et al.*, (2000), with significant delays in fruit ripening following 1-MCP treatment (Fig. 7). This was apparent with the 1-MCP treated fruit was however most apparent with the combined effect of both CA and 1-MCP.

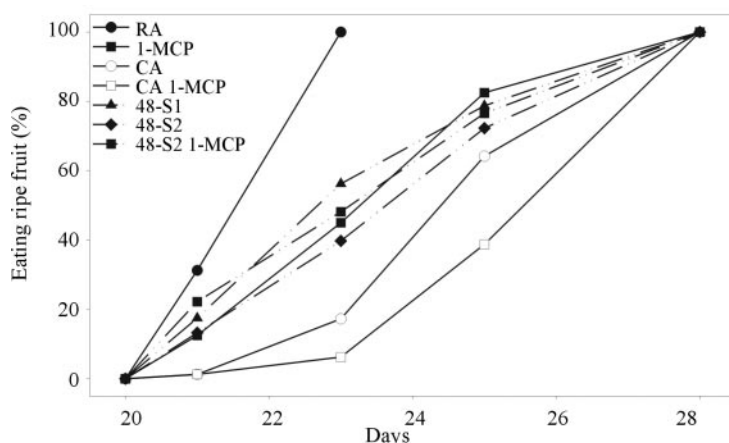
## CONCLUSION

The use of  $CO_2$  shock atmospheres as has been shown in the data shows little promise as it seems to primarily damage the fruit. However, levels of  $CO_2$  not as extreme or for shorter periods of time could prove to be more applicable to the storage of avocados.

1-MCP has been shown for many years now to be an important tool for the control of ethylene responses over extended periods of time. It is however still not commercially available thus much still needs to be

learned to what extent it can control ethylene responses in plants.

When considering the proposed hypothesis the conditions were all met to varying degrees when compared to the RA treated fruit with regard to extending shelf life and improving firmness. For use on 'Fuerte' avocados the Transfresh CA atmosphere shows much promise with regard to disorders, firmness and shelf life. However, on a cultivar which shows little tendency to disorders during cold storage, such as 'Hass', the levels of  $CO_2$  and  $O_2$  need to be refined to compare well with RA treated fruit with regard



**Figure 7. Ripening peaks of 'Hass' avocado fruit stored at 5.5°C for 18 days and at 20°C for 7 days under regular atmosphere (RA), controlled atmosphere (CA) and two carbon dioxide shocks for 48 hrs (eg. carbon dioxide shock no. 2 for 48 hours 48-S2) and three relevant 1-MCP treatments.**

to disorders as well as retaining firmer fruit and the extended shelf life.

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