

Avocado Postharvest Quality

Continuing Project: Year 5

*Project Leader: Mary Lu Arpaia (559) 646-6561
e-mail: arpaia@uckac.edu
Dept. of Botany and Plant Sciences, UC Riverside
Kearney Agricultural Center, 9240 S. Riverbend Ave., Parlier, CA 93648*

*Research Collaborators: Allan Woolf and Anne White
Quality Systems - HortResearch
Mt Albert Research Centre, 120 Mt Albert Rd, Private Bag 92 169
Auckland, New Zealand*

*Cooperating Personnel: J. Sievert, S. Collin, K. Fjeld, M. Coetzer, D. Stottleyer (UC, Riverside)
and Cecilia Requejo, Richard Jackman (Hort Research)*

Benefit to the Industry

This project will help to maintain and enhance the California avocado industry by continuing the postharvest evaluation on patented and unreleased varieties, continuing the examination of factors involved in postharvest decay development continuation of our collaborative effort to examine the impact of temperature and carbon dioxide on the ripening quality of 'Hass' avocado and initiation of research to further examine the susceptibility of avocados to mechanical injury following harvest. The final objective is to continue our adaptation of 2 postharvest manuals developed in New Zealand for the California industry for use in standardization of terminology and measurement of fruit quality at the packinghouse, wholesale and retail levels.

Each of these project objectives will assist the California avocado industry in shipping fruit of high quality to the consumer. This in turn will assist the grower to maximize their profit potential and further build a market identity for California avocados as fruit of the highest quality. This is critical as the California industry faces increased competition in the domestic market and elsewhere. The research expertise of the project team includes individuals trained in postharvest physiology (Arpaia, Woolf, and White), sensory evaluation (Collin), postharvest pathology (Sievert) and postharvest engineering and transit research (Thompson and Slaughter).

Objectives

- A) To continue a postharvest evaluation program on plant material from the breeding program.
- B) Initiate a collaborative study with HortResearch to examine avocado oil in Hass and new selections from the breeding program.
- C) Continue a collaborative study with A. Woolf and A. White to examine the effects of high temperature (>68°F) and carbon dioxide on the ripening behavior and quality of 'Hass' avocado.
- D) Evaluation of susceptibility of 'Hass' avocado to mechanical injury during ripening and handling.

- E) Continue adapting AvoCare Quality Assessment Manual and Identification Handbook for California conditions in collaboration with A. White, A. Woolf, the CAC Merchandising Staff and interested packers.

Summary

Continue a postharvest evaluation program on plant material from the breeding program.

Postharvest evaluation of the ‘Harvest’ and ‘Gem’ varieties, which were released in 2003 from the breeding program, was conducted using ‘Hass’ as a standard for each test. Fruit was obtained from the variety trial at UC Lindcove Research and Extension Center in Exeter on January 21, 2004 and stored for either 0, 3, or 6 weeks at 41F. Fruit was also obtained from the DeBusschere Ranch Variety Trial in Oxnard and the Hardison Ranch near Santa Paula on March 21, April 20, May 19, June 14 and August 4, 2004.

Fruit samples from all harvests were presented to volunteer panelists using protocols described previously in our annual reports. Dry weight on each fruit was also recorded so we can correlate the average sensory score for each fruit with the dry weight. Additionally, fruit harvest in April, June and August were either snapped or clipped harvested and stored for either 0 or 3 weeks at 41F. Fruit were then treated either with 0 or 50 ppm ethylene following storage.

Storage quality this season was mixed with no particular variety showing an advantage over the other. The most significant observation this season was related to ‘Harvest’ fruit obtained from the UC Lindcove Research and Extension site. A high percentage of fruit exhibited abnormal hardening around the seed cavity (Figure 1a). The Project Leader observed this disorder on the ‘Harvest’ in Israel in 1999 and similar symptoms have been reported from South Africa (Figure 1b). This disorder is present at harvest and is not induced by storage. David Stottlemeyer at UC, Riverside has not observed this problem previously over the several years that he has conducted fruit evaluation tests on the ‘Harvest’. We also checked with the researchers in Israel and South Africa to see if this problem has recurred and were informed that it had not. At this time we do not have any information on what may induce this disorder.

Figure 1. a. Internal symptoms of brown discoloration around the seed cavity of ‘Harvest’ at the time of harvest. Fruit harvested in December 2003 from UC Lindcove Research and Extension Center. A large percentage of the fruit exhibited this problem both in the unripe and unripe state. b. Similar internal problems on the ‘Harvest’ variety grown in South Africa from the 2002 season. Photo courtesy of Sylvie Kremer-Köhne of the Merensky Technological Services, South Africa.



a.



b.

Initiate a collaborative study with HortResearch to examine avocado oil in Hass and new selections from the breeding program.

Four avocado fruit were collected from each of four cultivars, ‘Hass’, ‘Lamb Hass’, ‘Gem’ and ‘Harvest’. Fruit were sampled May 21, 2004 from the DeBusschere variety block near Oxnard and again on August 4, 2004. In August we also collected samples from the Hardison site near Santa Paula (with the exception of ‘Harvest’). Within 24 hours of harvest unripe tissue was sampled (no skin or seed) from the equatorial part of each fruit using the Hofshi coring machine. Tissue samples were then freeze-dried, stored in nitrogen flushed foil bags and on 14th September 2004 transported to HortResearch in New Zealand where they will be used to extract oil. The average dry weights (determined by freeze drying) are reported in Table 1.

Table 1. Average harvest dry weights of fruit used for oil analysis. Dry weight determined by freeze drying.

Variety	Location	21-May-04	4-Aug-04
Gem	DeBusschere	27.91	34.75
Harvest	DeBusschere	23.77	25.51
Hass	DeBusschere	31.77	33.73
Lamb Hass	DeBusschere	23.76	29.84
Gem	Hardison	ns	33.22
Harvest	Hardison	ns	28.73
Hass	Hardison	ns	30.77
Lamb Hass	Hardison	ns	25.73

At HortResearch each sample will be ground to a powder and oil will be extracted using an accelerated solvent extractor machine ASE® 300 (Dionex). The ASE® provides automated extraction of 12 samples. The ASE® process consists of a closed stainless steel cell where the ground sample is placed and filled with organic solvent (Hexane). The cell is subjected to high pressure and temperature and the solvent and oil are pumped through to a collection bottle for further solvent evaporation and oil recovery. Substantially shorter extraction times than conventional oil extraction methods can be achieved with the ASE®. Technique optimization using the ASE® is currently underway to ensure that oil recovery is comparable to that of standard methods and to minimize any degradation of the healthy compounds in the oil.

The oil extracted from the samples will be analyzed to determine total oil content and composition in terms of fatty acid make up and other compounds noted to have health benefits, such as, levels of beta sitosterol and alpha tocopherol (vitamin E).

Evaluation of susceptibility of ‘Hass’ avocado to mechanical injury during ripening and handling.

We began our studies to validate the results of Arpaia et al. (1987). A preliminary evaluation of fruit susceptibility to compression damage was conducted in August 2003. The threshold for noticeable damage appears to be in the 5 to 10 lbf range. Unfortunately, this is the same “ripe” range targeted in most avocado ripening programs. We are collaborating with J. Thompson (Agricultural Engineering, UC Davis) to evaluate alternative package designs to reduce injury to

ripe avocado. Progress on this part of our research program has been frustrating. We conducted a series of studies in late Spring and Summer 2004 where fruit were either vibrated, compressed or impacted at varying ranges of firmness. Problems include difficulty in predicting how fast the fruit will reach a predicted range of flesh firmness and also difficulty in obtaining reproducible results that mimic damage observed at the retail level. In August 2004 we conducted 2 tests where we ripened fruit to firm-ripe to ripe. We then asked our volunteer panel to estimate how long it would be for an individual fruit to be “eating-ripe”. In this manner each panelist needed to handle the fruit. We then finished ripening the fruit and evaluated the fruit for internal damage. The results confirm that partially ripe fruit are most likely the most susceptible to damage but there was great variability between panelists and between individual fruit within a firmness category. We plan to make this portion of the project a major objective for the upcoming year. We had hoped to continue testing a modified package/tray with our UC, Davis collaborators but this has been delayed. We reported last year that this modified package showed promise in reducing transit damage to partially ripened fruit.

Adapt AvoCare Quality Assessment Manual and Identification Handbook for California conditions in collaboration with A. White, A. Woolf, the CAC Merchandising Staff and interested packers.

Two publications have been produced for use in identifying and rating postharvest disorders of New Zealand and Australian ‘Hass’ Avocados: ‘The AvoCare Assessment Manual’ and the ‘Handbook of Postharvest Disorders of ‘Hass’ Avocados’. Both manuals provide high quality photographs and clear descriptions of avocado disorders. In addition, these manuals discuss a range of possible causes for the disorders. The reason for production of two manuals is that the Handbook (a smaller document) was intended for use by the wholesale and retail segments of the industry, primarily for identification of disorders rather than determining the severity of disorders. These manuals provide a means to communicate accurately any problems that are observed with quality, rather than using terms such as “cut black”, which might describe many disorders. The internal quality disorders have been categorized into two groups: common and less common disorders.

The intent of this objective is to modify and adapt both the ‘AvoCare Assessment Manual’ and the ‘Handbook of Postharvest Disorders of ‘Hass’ Avocados’ for use by packers, merchandisers, receivers and other postharvest researchers in California. This effort is a continuation of our collaborative efforts, and it will bring postharvest terminology of avocado to a common ground for all interested parties. This objective will be achieved with input from the CAC Merchandising Staff, and other industry and research personnel.

There have been several stages in the development of the assessment manual, which has been called ‘The International Avocado Quality Manual’. The first version of ‘The International Avocado Quality Manual’ (Version 1.1) included three additional sections; preharvest damage, other commercial cultivars and postharvest damage scenarios. Feedback was obtained from a wide range of people including CAC staff, packers, wholesalers, importers and processors during Allan Woolf’s visit to California in 2002. The response of industry personnel was very positive and a number of changes were made to the manual, resulting in version 1.2. This version was further revised following input from potential users of the manual during Anne White’s study visit to California later in 2002.

Version 1.3 of 'The International Avocado Quality Manual' was then shipped to California, where a number of commercial and research personnel "road tested" the manual in a wide range of commercial and research settings. Further refinements/suggestions were then incorporated into the manual. Finally, following a review by the CAC Merchandising Department, California avocado industry players, and two academic reviewers (Gordon Mitchell and Adel Kader), additional changes were incorporated into the final version of the manual. The manual was promoted at the World Avocado Congress in Spain in October 2003. A booth was commissioned by HortResearch at the congress, and staffed by Anne White with assistance from Mary Lu Arpaia and David Stottlemeyer. A number of copies of the manual were on display for participants to view, and advance orders for the manual were taken.

'The International Avocado Quality Manual' will be printed within the next 3 months and will be available for purchase. Orders can be placed by contacting the following email address: intavomanual@hortresearch.co.nz. The cost of the manual is USD 75 plus postage and handling.

Revision of 'Handbook of Postharvest Disorders of 'Hass' Avocados' for California requirements has not proceeded as planned. Instead we have spent time and legal costs in helping to develop the 'Retail Quality Assessment Manual' sponsored by California Department of Agriculture's Buy California Program (50 copies for one-off printing and use in California only). This has involved providing the CAC with both text and photographs.

Continue a collaborative study with A. Woolf and A. White to examine the effects of high temperature (>68F) and carbon dioxide on the ripening behavior and quality of 'Hass' avocado.

Activities in this part of the project were divided between the 2 research teams.

Ethylene influence on fruit ripening.

The Arpaia group conducted 2 tests to further examine the influence of storage temperature on the fruit's ability to respond to ethylene treatment. These tests were conducted on May 24 and August 19 using fruit harvested from a commercial grove in Ventura County. The fruit were divided into 2 tests. The first test examined the response of the fruit to ethylene prior storage at 41F and had the following variables:

Ethylene treatments at 68F (20C): 0, 24, 48 hours PRIOR to storage
Storage duration following ethylene treatment: 0, 7, 14, 21 days
Storage temperature: 32-34 F; 41-42 F; 50-52F (0-1 C, 5-6C, 10-11C)
Sample size: 15 fruit per treatment combination

The second test examined the response of the fruit to ethylene following storage and had the following variables:

All fruit stored at 41F (5C)
Ethylene treatments at 68F (20C): 0, 24, 48 hours FOLLOWING storage
Storage duration: 0, 7, 14, 28 days
Sample size: 15 fruit per treatment combination

We have recently completed the fruit evaluation from the August test and are entering the data for analysis. Results of these tests will be presented at the Annual meeting.

Carbon dioxide influence on fruit ripening

The second portion of the objective deals with a continuation of research begun in New Zealand in 2002 examining the influence of elevated carbon dioxide on fruit quality. There is increasing use of ethylene ripening treatment of avocados before placement on the retail shelf. The goal is to present consumers with high quality, ripe or nearly ripe fruit at the time of purchase. This practice results in increased sales and consequently is becoming a widely accepted industry practice. Achieving predictable stages of ripening with minimal variability between fruit is also a key outcome. Although the use of ethylene to accelerate and synchronize avocado fruit ripening (“triggering”, “pre-conditioning”, “ethylene conditioning”, or “pre-ripening”) has been in use for many years, there are a number of factors related to its use that have not been adequately investigated.

During ripening of avocados, respiration increases significantly and CO₂ production is very high (Eaks, 1978). Accumulation of CO₂ in ripening rooms is likely to inhibit ethylene action (Lange and Kader, 1997; Metzidakis and Sfakiotakis, 1989), and may also have a negative effect on ripe fruit quality. Although it is commonly recommended that the CO₂ level should be maintained below 1% during the ethylene treatment process (U.S. Patent No. 4,764,389, LaBarge), commercial practice often does not achieve this. Thus it is important to ascertain the effect of increased CO₂ levels on ethylene treatment efficacy (in terms of both time to ripening and variability of ripening) and fruit quality. In New Zealand and California, results from preliminary observations of CO₂ levels in commercial ethylene treatment facilities indicated that concentrations between 2% and 6% CO₂ were common.

Research undertaken in California in June 2002 found that exposing fruit to CO₂ levels of 5% and 10% during a 48-hour ethylene treatment (100 ppm) resulted in a reduced rate of softening, and increased fruit-to-fruit variability in the time taken to attain eating ripeness. Fruit quality was slightly reduced because of increased rots and uneven ripening of the flesh. These treatments were carried out using a flow-through system, so that fruit were exposed to a specific CO₂ and ethylene concentration for the entire treatment period, and oxygen was not depleted. Ethylene ripening of avocados in a static system, as opposed to a flow-through system, would result in a concomitant decrease in O₂ as respiration rate of the fruit increased.

The Arpaia group also conducted 2 tests examining the influence of elevated carbon dioxide on fruit ripening. This work mirrored the studies conducted in New Zealand by the Woolf group. The objective of this portion of our work was to determine the influence of elevated carbon dioxide (CO₂) and reduced (O₂) levels during ethylene treatment of 'Hass' avocados on both the time to ripen and overall fruit quality.

The California tests used fruit obtained from a commercial packinghouse and were conducted on April 29 and September 16. We were not able to control the oxygen levels in this study as previously planned due to problems with the gas mixing system and the unavailability of sufficient stations for the experiment. We are still collecting data from the second test and will need to enter and summarize the data before results can be presented. The variables which we examined were:

- All fruit stored at 41F (5C)

- Ethylene treatments at 68F (20C): 0, 48, 96 hours FOLLOWING storage

- Ethylene concentration: 0, 1, 10, 100 ppm

- Carbon dioxide concentration during ethylene treatment: 0, 5, 10%

- Storage duration: 0, 1.5 and 3 weeks

- Sample size: 15 fruit per treatment combination

Results from the Woolf group (Anne White, Cecilia Requejo, Richard Jackman and Allan Woolf) is presented below.

During the 2003/04 season, work has been carried out in New Zealand to examine the effect of both CO₂ accumulation and O₂ depletion during treatment at a range of ethylene concentrations, on rate of ripening and fruit quality of 'Hass' avocados. We had also planned to investigate the influence of CO₂ accumulation and O₂ depletion during continuous treatment for up to 5 days at a lower ethylene concentration (~10 ppm), but were unable to carry out the research due to a shorter than normal harvest season and thus reduced fruit availability. We plan to carry out this work with early season fruit (dry matter of \cong 26%) in October 2004.

Materials and Methods

In December 2003, fruit were sourced from three orchards (dry matter at harvest ranged from 30.3 to 32.7% for the 3 orchards) and ethylene treatment was carried out two days after harvest. Ethylene treatments were carried out at 20°C (68°F) over a 48-hour period using a flow-through gas system to attain 1, 10, 50 or 100 ppm ethylene in the treatment chamber. Maximum CO₂ and minimum O₂ levels targeted over the ethylene treatment period were <0.5% CO₂ / 21% O₂, 2.5 CO₂ / 18% O₂, and 7.5% CO₂ / 15% O₂. These gas combinations were based on previous research results that had shown the level to which O₂ was reduced as CO₂ levels increased.

Air and fruit temperatures were monitored using data loggers from the time fruit were collected from the packhouse until all fruit were ripe. Gas samples were taken from the chambers on 20 occasions during treatment for analysis of ethylene, carbon dioxide and oxygen concentrations and flow rates were adjusted as necessary to obtain required gas levels.

Fruit firmness and skin color was measured on up to 45 fruit per treatment (15 fruit per orchard line), 3 days after removal from ethylene treatment. To provide an objective measure of fruit firmness, a digital Firmometer (White et al., 1999) with a 200 g weight was used. The Firmometer value derived (0-110) is the Firmometer reading (mm displacement) multiplied by 10. As fruit soften, Firmometer values increase. Skin color was rated by eye using a 6-point rating scale (1=emerald green to 6=fully black).

Fruit were ripened at 20°C (68°F) and when fully ripe (approximate puncture value of 1 lbf using an 8 mm Effegi head or Firmometer value of 80 using 200 g weight, White et al., 1999) were assessed for external and internal quality.

Fruit Quality

Fruit were assessed for quality when designated as ripe. This was assessed daily by gentle hand-squeezing by a trained assessor. When each fruit became ripe, the number of days taken to ripen once out of ethylene treatment (days to ripe; DTR) was recorded, and fruit quality assessed. Skin color was rated by eye and the fruit were cut longitudinally into quarters, peeled, and the following factors evaluated:

- stem end rots (SER; rots entering only through the fruit peduncle)
- body rots (BR; rots entering through the skin)
- vascular browning (browning of the vascular strands running longitudinally through the fruit tissue)

- uneven ripening (uneven flesh softening such that flesh tissue adhered to the seed when fruit was cut in half, or there were hard areas of flesh in otherwise soft tissue. This was determined by pricking with a toothpick or knife)
- flesh adhesion to skin (a thin layer of fruit pulp adheres to the skin when the skin is peeled back).

Each factor was rated on a scale of 0 to 3 increasing in half units where 0 = no occurrence; 1 = 10% of fruit affected; 2 = 25% of fruit affected; 3 = 50% or more of fruit affected. A factor rating ≥ 2 was regarded as unacceptable. The International Avocado Quality Manual (White et al., 2004) provides full details and photographs of the rating system for each disorder. Each fruit was recorded as ‘sound’ (acceptable to the consumer) or not. This was determined by taking into account the overall quality of the whole fruit at the time of assessment.

Data presentation and analysis

Fruit quality data is presented with the level of the disorders expressed as either the “incidence” of the disorders using the proportion of fruit with any level of the disorder (i.e. >0 rating) or secondly, the proportion of fruit with an unacceptable level of the disorder (i.e. ≥ 2). The latter is described as the disorder “severity”. All data is presented as the mean percentage for the treatment. Data were analyzed by analysis of variance, using the Genstat 7 statistical package. Disorder data is proportional (percentages), therefore it must be transformed by angular transformation before analysis i.e. $\arcsin(\sqrt{x})$. The analysis of variance was performed on the transformed data and LSDs (Least Significant Difference) apply to the transformed means only. To compare statistical differences between means, Fisher's or Tukey's LSD values were calculated, at the 5% level, from the standard errors of difference. Back-transformed rather than transformed means are presented. The LSDs apply to the transformed data, and thus cannot be presented. Therefore, to indicate statistical differences, means followed by the same letter are not significantly different from each other.

Results

Fruit Softening

Fruit were consistently firmer (Firmometer values decreased) as the amount of CO₂ increased and O₂ decreased in the environment during ethylene treatment (Tables 2 and 3). The significance of the effect of CO₂/O₂ levels on softening was greatly influenced by the ethylene concentration, with the largest effect being at 10 ppm ethylene (Table 2). Fruit exposed to 7.5% CO₂ / 15% O₂ during ethylene treatment at 10 ppm were significantly firmer than fruit exposed to 2.5% CO₂ / 18% O₂, which in turn were significantly firmer than fruit exposed to 0.5% CO₂ / 21% O₂. Fruit exposed to the higher CO₂ and lower O₂ levels also took longer to reach eating ripeness than fruit exposed to low CO₂ and high O₂ levels (up to 1.5 days longer, Table 4). As ethylene concentration increased above 10 ppm, the effect of CO₂ and O₂ on fruit softening was less pronounced.

On average, fruit ripened at an ethylene concentration of 10 ppm and above softened significantly more quickly than fruit ripened at 1 ppm ethylene (approximately 5 days to ripen at 10 ppm versus 9 days at 1 ppm, Table 4).

The CO₂/O₂ levels during ethylene treatment affected the spread of ripening within each treatment (i.e. the fruit-to-fruit variability in time to ripen, Figure 2). Increased CO₂/decreased O₂ resulted in a flatter distribution curve, and thus more variable ripening compared with fruit exposed to 0.5%

CO₂ / 21% O₂. Ethylene treatment at 10 ppm or greater resulted in ripening beginning earlier, and a more compact distribution (i.e. less variable) than when fruit were treated with 1 ppm ethylene.

Skin color

Five days after the beginning of ethylene treatment, fruit were rated as greener by eye (lower skin color rating) with increasing CO₂/decreasing O₂ concentration (Tables 2 and 3). As with fruit softening, the effect was most significant for fruit treated with 10 ppm ethylene. When fully ripe the skin color of the ethylene-treated fruit tended to be darker (higher rating) with increasing CO₂/decreasing O₂ concentration.

Ripe fruit quality

The overall quality of the fruit was fairly high (80 to 99% sound fruit). Increased CO₂ / reduced O₂ levels during ethylene treatment reduced the proportion of sound fruit (Table 4). Fruit exposed to higher CO₂ / reduced O₂ tended to have a higher incidence of stem end rot and body rot than those exposed to lower levels of CO₂ / increased O₂ during ethylene treatment (Table 4). This trend of reduced quality at higher CO₂ levels may be exacerbated when there is greater rot pressure, for example after rain (Smilanick and Margosan, 2001), or where fruit have been stored for significant periods before ethylene treatment. Uneven ripening and flesh adhesion to skin occurred at a very low incidence of less than 1% (data not presented).

Fruit treated with 1 ppm ethylene took significantly longer to ripen than fruit treated with higher ethylene concentrations (approximately 8 days at 1 ppm compared with about 5 days at ≥ 10 ppm). There was a concomitant decrease in ripe fruit quality, whereby fruit treated with 1 ppm ethylene had a significantly higher incidence and severity of rots and vascular browning than fruit treated with 10, 50 or 100 ppm ethylene (Table 4). Fruit that take longer to ripen tend to have a higher incidence and severity of rots (Hopkirk et al., 1994).

Orchard source had minimal influence on ripening rate, skin coloration and ripe fruit quality (<1% of variability was due to orchard source).

Discussion

An ethylene concentration of 1 ppm is non-saturating meaning that the rate of ripening is not maximal. This is supported by the present data (Tables 2 to 4), where ethylene concentrations of 10, 50 and 100 ppm accelerated the ripening rate (as measured by fruit firmness, skin color and days to ripe) compared with 1 ppm ethylene, but were not significantly different from each other.

At this non-saturating ethylene concentration (1 ppm), the effect of increased CO₂/decreased O₂ on ripening rate and ripe fruit quality was very small. The greatest effect of increased CO₂/decreased O₂ levels was observed at an ethylene concentration of 10 ppm where both firmness (Firmometer value and days to ripen, DTR) and skin coloration were significantly affected. At CO₂ levels of 2.5% and higher, fruit were significantly firmer and more green-colored five days after ethylene treatment, and fruit took, on average, more than one day longer to ripen than fruit exposed to 0.5% CO₂/21% O₂. Ripe fruit quality was also reduced at CO₂ levels of 2.5% and higher, whereby increased rots resulted in less sound fruit.

However, at higher ethylene concentrations (50 and 100 ppm) the effect of CO₂/O₂ was reduced, such that a CO₂ level of 2.5% had little effect on fruit softening, skin coloration and ripe fruit quality. However, a higher CO₂ level of 7.5% resulted in a statistically significant reduction in ripening rate (firmer and less colored fruit, and increased days to ripen) and a slight reduction in ripe fruit quality because of increased rots.

Conclusion

Exposing fruit to increased CO₂ and decreased O₂ levels during ethylene treatment resulted in a reduced rate of softening and increased fruit-to-fruit variability in the time taken to attain eating ripeness. Fruit quality was slightly reduced because of increased rots. The greatest effect of increased CO₂ and decreased O₂ levels was observed at an ethylene concentration of 10 ppm. This has implications for ethylene ripening facilities where ethylene is being applied at relatively low concentrations. Based on these and previous results, it is recommended that CO₂ levels during ethylene treatment should be maintained below 1-2% where ethylene concentrations of 10 ppm are applied, but 2.5% CO₂ levels should be acceptable if higher ethylene concentrations are used (100 ppm).

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Table 2. Effect of CO₂ /O₂ concentration during ethylene treatment (48 hours at 20°C (68°F)) on avocado softening, as measured by the digital Firmometer (200 g weight), and skin color, as rated by eye (1=emerald green to 6=fully black) 5 days after the start of ethylene treatment. Data presented is for orchard 2 only and those means followed by different letters in the same column within each ethylene level are statistically significant at p<0.05.

Treatment		Firmometer value	Skin color
Ethylene (ppm)	CO ₂ /O ₂ (%)		
1	0.5/21	20.6a	2.1a
	2.5/18	18.4a	2.0a
	7.5/15	18.7a	2.0a
10	0.5/21	72.4c	3.7b
	2.5/18	49.1b	2.9a
	7.5/15	35.6a	2.7a
50	0.5/21	84.8b	3.8a
	2.5/18	67.0a	3.7a
	7.5/15	64.4a	3.6a
100	0.5/21	73.4b	3.6ab
	2.5/18	69.4ab	3.7b
	7.5/15	62.9a	3.2a
LSD		8.55	0.41

Table 3. Effect of CO₂ /O₂ concentration during ethylene treatment (48 hours at 20°C (68°F)) on avocado softening, as measured by the digital Firmometer (200 g weight), and skin color, as rated by eye (1=emerald green to 6=fully black) 5 days after the start of ethylene treatment. Data presented is the average for the three orchards and those means followed by different letters in the same column within each ethylene level are statistically significant at p<0.05.

Treatment		Firmometer value	Skin color
Ethylene (ppm)	CO ₂ /O ₂ (%)		
10	0.5/21	66.4b	4.0b
	2.5/18	48.1a	3.5a
	7.5/15	43.8a	3.5a
100	0.5/21	63.1b	3.9b
	2.5/18	60.3b	4.0b
	7.5/15	51.8a	3.5a
LSD		5.50	0.26

Table 4. The effect of CO₂/O₂ concentration during ethylene treatment (48 hours at 20°C (68°F)) on days to ripe (DTR), skin color when ripe and the incidence and severity of rots (stem end rot and body rot), and vascular browning (VB). Fruit were assessed for quality when ripe (equivalent to a puncture value of 1 lbf using an 8 mm Effegi head or an average Firmometer value of 80 using a 200 g weight). Incidence = proportion of fruit with any disorder i.e. rating > 0. Severity = proportion of fruit with an unacceptable level of the disorder i.e. rating ≥ 2. Average back-transformed values for the 3 orchards are presented and those means followed by different letters in the same column, for each ethylene concentration are statistically significant at p<0.05.

Treatment				Incidence (%)				Severity (%)		
Ethylene (ppm)	CO ₂ /O ₂ (%)	DTR	Skin color	Sound	Stem End Rot	Body Rot	VB	Stem End Rot	Body Rot	VB
1	0.5/21	8.7a	4.5a	81.0a	31.2a	56.6a	12.6a	6.5a	19.2a	8.5a
	2.5/18	9.1b	4.6a	80.4a	46.9b	51.8a	23.6b	7.7a	14.5a	19.2b
	7.5/15	9.2b	b 4.6b	86.5a	48.7b	44.8a	16.4a b	10.3a	9.7a	13.7ab
10	0.5/21	4.3a	4.4a	99.4b	6.2a	22.6a	0.6a	0a	0.8a	0.1
	2.5/18	5.4b	4.5a	93.5a	10.5a	32.1a	3.9a	2.3a	4.6ab	1.1
	7.5/15	5.9c	4.6b	93.6a	11.4a	32.1a	2.5a	2.0a	13.1b	0.2
50	0.5/21	4.7a	4.5a	99.1b	8.5a	27.7a	0.9a	0a	1.8a	0
	2.5/18	4.7a	4.5a	98.4b	7.7a	24.2a	0.1a	0a	3.1a	0
	7.5/15	5.3b	b 4.6b	89.9a	11.4a	35.2a	1.1a	2.3a	17.7b	0.1
100	0.5/21	4.7a	4.5a	97.8a	7.7a	24.8a	0.2a	0.5a	1.8a	0
	2.5/18	4.9a	4.6b	97.5a	7.2a	24.5a	0.3a	1.2a	3.5a	0.1
	7.5/15	5.5b	4.5a b	95.3a	18.5b	32.3a	1.1a	0.5a	4.2a	0
LSD		0.28								

Figure 2. The number of fruit evaluated as being ripe on each day during ripening at 20°C after ethylene treatment. Fruit were treated with 1, 10, 50 or 100 ppm ethylene (E) at a range of CO₂/O₂ levels.



