Avocado Postharvest Quality

Continuing Project; Year 5 of 5

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Benefit to the Industry

This project will help to maintain and enhance the California avocado industry by continuing a project evaluating the potential of snap harvesting and initiating postharvest evaluation on patented and unreleased varieties. 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, White), sensory evaluation (Collin) and postharvest pathology (Smilanick, Margosan, Sievert).

Objectives

A. To continue a postharvest evaluation program on the unreleased plant material from the breeding program.
B. To continue collaboration with J. Smilanick and D. Margosan examining factors involved with postharvest decay of avocado.
C. Initiate 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.
D. 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.

Summary

As part of our collaborative research efforts, Allan Woolf spent two weeks during January 2002 in California. Two key aims of the visit were to review with a range of industry personnel the Avocado Assessment Manual (Objective D), and to carry out initial measurements of CO_2 levels in commercial ethylene ripening facilities (Objective C). There was a very positive response to the Manual with support from all key players. Two presentations were given to the meeting of the Avocado Quality Taskforce (Avocado Assessment Manual and 1-MCP treatments). Discussions on 1-MCP results to date and planning for assessment of a Chilean shipment (another collaborative project between HortResearch and Mary Lu Arpaia, funded by AgroFresh (Rohm & Haas)) were also worthwhile. Woolf and Arpaia visited over the two-week period with packinghouses (Mission, Eco Farms, Henry, Del Rey, Index), the Calavo processing plant and corporate offices, the LA Produce Market, the Vons' Distribution Center, avocado orchards, the UC Riverside Campus, UC Kearney Agricultural Center (Parlier), USDA (Parlier) and CAC staff (Merchandising VP, Jan DeLyser and G. Witney). The visit reinforced and established important relationships with CAC staff, Reuben Hofshi and Joe Smilanick. Anne White was invited by Dr Joe Smilanick of USDA to spend 3 months, from mid April to mid July, in California on a study visit. During her stay Anne worked with both Smilanick and Arpaia on their avocado research projects. Results of our collaborative work on carbon dioxide effects during ethylene conditioning are reported below.

Objective A. To continue a postharvest evaluation program on the unreleased plant material from the breeding program.

Postharvest evaluation of the unreleased material from the breeding program including sensory evaluation using 'Hass' as a standard for each test was conducted twice during the season. Fruit was obtained from the breeding block at UC South Coast Research and Extension Center in Irvine as well as the DeBusschere Ranch in Oxnard. The following varieties were stored for 0, 3, 6 weeks using standard protocols for fruit evaluation; 'Hass', 'Gem', 'Harvest', 'Lamb Hass', 'Marvel', and 'Nobel'. Data collection was completed in September 2002.

Objective B. To continue collaboration with J. Smilanick and D. Margosan examining factors involved with postharvest decay of avocado.

Postharvest identification of disease organisms causing avocado decay was coordinated with USDA researchers. We collaborated on 2 experiments this season to identify factors involved in postharvest decay of 'Hass' avocado and the influence of fruit storage on disease susceptibility. These results are discussed in J. Smilanick and D. Margosan's progress report.

Objective C. Initiate 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.

<u>Background.</u> There is increasing emphasis on fruit treatment with ethylene prior to marketing of the fruit. The goal is to present consumers with fruit that are ripe or nearly ripe, and are of high quality in the marketplace. Although the use of ethylene to accelerate and synchronize avocado fruit ripening ("triggering', "preconditioning", "ethylene conditioning", or "pre-ripening") has been in use for many years there remain a range of aspects that have not been adequately investigated. In addition, although recommendations have been made in terms of temperature and CO_2 levels, commercial practice often does not achieve these goals, and it is important to ascertain the effect of such deviations on ethylene treatment efficacy and fruit quality. This study was prompted from initial observations on fruit pulp temperatures recorded at CA packinghouses in 2000 and additional conversations with other packers. We observed insufficient control of fruit pulp temperature during the "triggering" of the fruit that resulted in temperatures in excess of 70F. Also, since avocados produce large quantities of CO_2 as they ripen, CO_2 levels can accumulate in ripening rooms which is likely to inhibit ethylene action, and may also have a negative effect on ripe fruit quality.

<u>*High temperature effects on 'Hass' fruit quality.*</u> We conducted six tests to examine the influence of short duration high temperature exposures with or without ethylene on fruit ripening and storage quality. The first test, conducted in January 2002 was a preliminary experiment to test the chambers which were designed by J. Sievert and K. Fjeld. The remaining 5 experiments were conducted beginning in late February 2002. We modified the experimental design in the subsequent tests based on the results of the January test and input from Allan Woolf during his February 2002 visit. All fruit were harvested from the same set of trees from an orchard near Fillmore in Ventura County. The fruit were size picked (size 48) in the morning. The harvested fruit were transported to UC Kearney Agricultural Center (UC-KAC) and held overnight at 41F. The following morning the fruit were sorted and 15 fruit each randomly assigned to the experimental treatments. All treatments were initiated within 1 day of harvest. Air and fruit temperatures were monitored using Hobo data loggers from the time fruit were harvested until all fruit were ripe. When fruit were treated with ethylene (~40 ppm), this was done using a flow through system. The carbon dioxide concentration was maintained below 1%.

Fruit were monitored on a daily basis during the ripening process so that we could have a record of the "days to ripe" as well as a measurement of weight loss. When ripe, as judged by "feel" of the fruit, ripeness was confirmed using hand pressure rating (1-7 scale) and penetrometer measurements (2 measurements per fruit). Each ripe fruit was externally rated for visual shrivel, overall appearance, peel color (1 – 6) and signs of decay. The fruit was then cut longitudinally and rated for off-odor (presence/absence), flesh appearance (watery, creamy or dry), flesh adhesion to the seed (0 – 3), seed germination (yes/no), stringiness (yes/no), flesh and/or vascular discoloration (0 – 3), stem end rot (0 – 3), and stem end vascular streaking (0 – 3). Any other physiological disorder was also noted. One half of the fruit was then peeled and rated for ease of peeling (0 – 3) and the incidence of body rots (0 – 3).

Tables 1 through 3 report selected ripe fruit characteristics from Tests 2 - 6. We have not yet statistically analyzed the data, however, certain trends are apparent in the dataset. Table 1 reports the data from fruit that were immediately ripened following high temperature (+/- ethylene) exposure. The data shown here is the average for all tests (February – August 2002). In general, there is a trend to longer ripening times as temperature increases. Ethylene during the high temperature treatment partially overcomes the negative influence of high temperature, but the most rapid ripening occurred when fruit were held continuously at 68F. Although high relative humidity was maintained, with increasing temperature, ripe fruit exhibited higher weight loss and more importantly greater visual shriveling. The most striking influence of even a 24 hour exposure to temperatures higher than 68F was the increased incidence of both stem end rot and body rots. This effect is greatest when comparing the ethylene treated fruit between temperatures. Table 2 presents the same ripe fruit characters following 14 days of 41F storage. The same trends presented in Table 1 also occur although the average "days to ripe" is less in all cases as compared to the "no storage" evaluations. The affect of fruit decay is again evident following ripening at 68F.

Table 3 presents the ripening characteristics of fruit held continuously at either 68, 77, 86 or 95F. At each temperature one half of the fruit had been treated with ethylene for 48 hours. In all cases, fruit held at 86 or 95F had inferior ripe fruit quality. Fruit ripened at 77F had similar weight loss and time to ripeness as the 68F treated fruit but exhibited higher levels of fruit decay following ripening.

These results from this first year both supports and expands research previously published by Eaks (1978) and Hopkirk et al. (1994). It highlights the importance of temperature management during the ethylene conditioning process and shows that excessive pulp temperatures during ethylene conditioning can indeed negatively impact ripe fruit quality.

High carbon dioxide exposure during ethylene conditioning. 'Hass' avocados (48-count size) were obtained from a commercial packinghouse in Santa Paula, California on two occasions (May 21 and May 29 2002). Fruit were sourced from 3 different commercial orchards on each occasion. After transport to UC-KAC, fruit were stored at 41F for 1 to 2 days until application of ethylene treatment at 68F for 48 hours. Air and fruit temperatures were monitored using Hobo data loggers from the time fruit were collected from the packinghouse until all fruit were ripe. Handling and ripening of fruit was carried out using commercial trays.

Fruit were removed from storage and re-warmed to 68F, over a period of several hours, before being randomized and sealed into the treatment buckets (5 gallon). Each gas treatment had three replicates (each treated in a different bucket) that contained 15 fruit (5 fruit per grower lot). The gas treatments were applied for 48 hours at 68F air temperature via a flow through system. Ethylene was applied at a concentration of 100 ppm and five concentrations of CO_2 were applied in the gas flow; 0.5, 1.2, 2.5, 5 and 10%. Air made up the remainder of the total gas flow (2200 ml/min). A non-ethylene control treatment of fruit in buckets at 0.5% CO_2 but with no ethylene was included.

Measurement of skin color can provide an indication of ripening, and its variability for 'Hass' avocados. Skin color was measured prior to ethylene treatment, and firmness and skin color were measured immediately after removal from ethylene treatment and after two days in air at 20ºC (68°F). Skin color was measured on 18 fruit per treatment (2 fruit per orchard line from each of the three buckets). Skin color was measured objectively using a Minolta Chromameter (3 averaged measurements around the fruit equator) and expressed in $L^*C^*h^o$ units. [L* = Lightness: Color brightness changing from light to dark (0 = black to 100 = white); C* = Chroma: Vividness. As chroma increases the color becomes more intense (0=dull to 60 most vivid); h° = Hue angle: The basic tint of color: 0°=red, 90°=yellow, 180°=green and 270°=blue.] Skin color was also rated by eye using a 6-point rating scale (1=emerald green to 6=fully black).

Fruit were ripened at 20ºC (68°F), relative humidity >85% and when fully ripe (approximate puncture value of 1lbf using an 8mm Effegi head or Firmometer value of 80 using 200g weight, White et al., 1999), assessed for external and internal quality in a similar fashion as described above.

Fruit softening. As expected, fruit that were not ethylene treated took significantly longer to soften than ethylene treated fruit (Table 4). Ethylene treated fruit were firmer (Firmometer values decreased) as the amount of CO_2 in the environment during ethylene treatment increased (Table 4). Fruit exposed to 10% CO_2 during ethylene treatment were significantly firmer than fruit exposed to CO_2 levels of 2.4% and less and took longer to reach eating ripeness (about 1 day longer). Although increasing CO_2 levels during ethylene treatment slowed ripening, on average, fruit still ripened significantly more quickly than non-ethylene treated fruit.

Although the level of CO_2 in the environment did not dramatically affect the average number of days taken to reach fully ripe, the spread of ripening within each treatment was affected (i.e. the fruit to fruit variability in time to ripen). Non-ethylene treated fruit had a normal shaped distribution of spread of days for fruit to reach fully ripe (Fig 1). Ethylene treatment with low levels of CO_2 resulted in a more compacted (i.e. less variable) but similar shaped distribution. Fruit exposed to 10% CO_2 during ethylene treatment had a skewed distribution due to the fact that a greater number of fruit were slower to ripen.

Peel color. Fruit that were not ethylene treated were rated as significantly greener by eye and measured by the Minolta chromometer as being significantly lighter (higher L), more vivid (higher chroma) and more green (higher hue angle) than ethylene treated fruit on each sampling occasion during ripening (Table 5). When fully ripe, the peel color of non-ethylene treated fruit was the same as ethylene treated fruit when rated by eye. At the end of ethylene treatment, fruit were rated as greener by eye and measured by Minolta as being significantly lighter (higher L), more vivid (higher chroma) and greener (higher hue angle) with increasing CO_2 concentration (Table 5). However, after a further 2 days ripening at 20ºC (68°F) there was no difference in the peel color of the ethylene treated fruit. Fully ripe fruit which had been exposed to 5 and 10% CO_2 during ethylene treatment were rated by eye as having slightly darker peel than fruit exposed to lower CO_2 concentrations and non-ethylene treated fruit.

Ripe fruit quality. The overall quality of the fruit was very high (90 to 99% sound fruit). High levels of CO_2 during ethylene treatment did not significantly reduce the proportion of sound fruit but there was a tendency for fruit exposed to 5 and 10% CO_2 during ethylene treatment to be of poorer quality than those exposed to lower levels of CO_2 during ethylene treatment (Table 6). Fruit exposed to 5 and 10% CO_2 tended to have a higher incidence and severity of stem end rot, body rot and uneven ripening of the flesh than those exposed to lower levels of CO_2 during ethylene treatment (Table 6). This trend of reduced quality at higher CO_2 levels may be increased when there is greater rot pressure, for example after rain (Smilanick and Margosan, 2001), or where fruit have been stored for significant periods prior to ethylene treatment. Long periods of storage can also result in physiological disorders such as flesh graying and vascular browning.

Although the non-ethylene treated fruit took significantly longer to ripen than ethylene treated fruit (8 days compared to 5 days, respectively), quality was not reduced. Fruit that take longer to ripen tend to have a higher incidence and severity of rots (Hopkirk et al., 1994). The occurrence of pink discoloration in the flesh or vascular tissue was significantly lower in non-ethylene treated fruit than ethylene treated fruit, regardless of the level of CO_2 during ethylene treatment (Table 6). Little is known about this disorder but it is thought to be influenced by preharvest factors (Thorp, 1997).

Orchard source had the most significant influence on ripening rate, skin coloration and ripe fruit quality (data not shown). There was no significant interaction between orchard and treatment, which indicates that even though fruit varied in their rate of ripening and internal quality according to orchard source, they responded in a similar manner to the treatment imposed.

Exposing fruit to CO_2 levels of 5% and 10% during ethylene treatment resulted in a reduced rate of softening and increased fruit to fruit variability in time taken to attain eating ripeness. Fruit were of slightly reduced quality due to increased rots and uneven ripening of the flesh. Based on these results a preliminary recommendation is that CO_2 levels during ethylene treatment should be maintained below 5%.

Objective D. 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 recently 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 include high quality photographs and clear descriptions of the disorders. In addition, these manuals discuss a range of possible causes of the disorders. The reason for production of two manuals is because 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 accurately communicate any quality problems observed, rather than terms such as "cut black" which might describe many disorders. The internal 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 will result in bringing postharvest terminology of avocado to a common ground for all interested parties. This objective will be achieved through input from the CAC Merchandising Staff and other industry personnel.

There have been several stages in the development of the comprehensive assessment manual, which has been called 'The International Avocado Quality Manual'. Firstly, feedback on the 'AvoCare Assessment Manual' was obtained from Drs. Mary Lu Arpaia, Joe Smilanick and Peter Hofman (DPI, Queensland, Australia) prior to the official project start date. From these comments a first version of 'The International Avocado Quality Manual' (Version 1.1) was developed which included three additional sections; preharvest damage, other commercial cultivars and postharvest damage scenarios. Figure 1 is an example of a common disorder, which includes a comprehensive rating scale and three photographs to illustrate increasing severity of the disorder. Figure 2 is an example of a less common disorder, which has a less detailed rating scale and one photograph to illustrate the disorder.

Version 1.1 was brought to California by Allan Woolf in January 2002 and feedback obtained from a wide range of people including CAC staff, packers, wholesalers, importers and processers. The response of industry personnel was very positive and a number of changes were made. Anne White, who was spending 3 months on a study visit with Joe Smilanick, brought Version 1.2 to California in April 2002. During Anne's visit input was obtained from a number of avocado researchers and additional work was carried out to measure softening of 'Hass' avocados using a range of methods including flesh puncture with an 8mm (0.3 inch) Effegi tip, which is the standard method of measuring fruit firmness in California.

In November 2002 Version 1.3 of 'The International Avocado Quality Manual' will be shipped to California where a number of commercial and research personnel will "road test" the manual in a wide range of commercial and research settings. At this time, a number of the existing "Handbooks" will be provided for use alongside the main assessment manual. Personnel who have used the manual and handbook will be consulted with and further refinements/suggestions collected regarding both manuals. These changes will be incorporated into final versions adapted to California needs by November 2003. It is the agreed aim of postharvest researchers in California, New Zealand and Australia that 'The International Avocado Quality Manual' should provide a step along a path to an international standard for fruit evaluation.

References:

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Table 1. Selected characteristics of ripe 'Hass' avocado following holding at 68, 77, 86 or 95F for either 0, 24 or 48 hours with or without ~40 ppm ethylene prior to ripening at 68F. Values reported are the average of data collected from fruit harvested February 25, April 8, May 21, July 8 and August 19, 2002 from Ventura County. Fruit harvested from the same group of trees each time. Following harvest, the fruit taken to UC-KAC and placed under postharvest treatment within 24 hours.

Treatment temperature (F)	Hours at temperature prior to ripening at 68F	Ethylene treatment (No/Yes)	Days to ripe	Shrivel (0-3)	Weight loss (%)	Peel Color (0-6)	Ripening uniformity (1-5)	Flesh to Seed (0-3)	Body rot (%)	Body rot severity $(0.5 – 3)^z$	Stem end rot (%)	Stem end rot severity $(0.5 – 3)^z$
68	0	No	13.93	1.25	5.19	4.94	4.33	0.30	6.68	0.20	17.36	0.80
68	*24*	*Yes*	*8.69*	*0.64*	*3.81*	*4.53*	*4.73*	*0.22*	*2.68*	*0.20*	*4.00*	*0.45*
68	*48*	*Yes*	*6.14*	*0.44*	*2.80*	*4.34*	*4.87*	*0.16*	*0.00*	-	*1.34*	*0.10*
77	24	No	14.07	1.19	5.52	4.69	4.23	0.31	8.00	0.60	21.34	0.90
77	48	No	14.41	1.42	5.49	4.84	4.30	0.32	13.32	0.60	26.68	0.90
77	*24*	*Yes*	*10.87*	*1.03*	*4.65*	*4.78*	*4.57*	*0.25*	*9.32*	*0.45*	*14.68*	*0.63*
77	*48*	*Yes*	*7.86*	*0.72*	*3.77*	*4.75*	*4.20*	*0.23*	*8.00*	*0.25*	*6.66*	*0.30*
86	24	No	14.69	1.63	5.67	4.77	4.25	0.26	14.66	0.80	21.32	0.82
86	48	No	15.30	1.32	6.07	4.55	4.46	0.29	6.66	0.45	23.78	0.86
86	*24*	*Yes*	*12.92*	*1.38*	*5.44*	*4.53*	*4.43*	*0.25*	*16.00*	*0.58*	*36.00*	*0.89*
86	*48*	*Yes*	*11.57*	*1.30*	*5.73*	*5.08*	*3.87*	*0.43*	*13.12*	*0.75*	*27.12*	*0.77*
95	24	No	15.43	1.55	6.48	4.81	4.49	0.23	9.32	0.35	25.32	0.86
95	48	No	17.08	1.48	6.99	4.73	4.37	0.21	4.02	0.40	34.24	1.11
95	*24*	*Yes*	*13.28*	*1.45*	*6.14*	*4.81*	*4.41*	*0.34*	*20.00*	*0.65*	*37.32*	*1.16*
95	*48*	*Yes*	*14.66*	*1.72*	*7.33*	*4.86*	*4.18*	*0.50*	*30.22*	*1.26*	*34.00*	*1.24*

^{z} Stem end rot and body rot severity for decayed fruit only.

Table 2. Selected characteristics of ripe 'Hass' avocado following holding at 68, 77, 86 or 95F for either 0, 24 or 48 hours with or without ~40 ppm ethylene prior to 14 days storage at 41F. Fruit ripened at 68F following storage. Values reported are the average of data collected from fruit harvested February 25, April 8, May 21, July 8 and August 19, 2002 from Ventura County. Fruit harvested from the same group of trees each time. Following harvest, the fruit taken to UC-KAC and placed under postharvest treatment within 24 hours.

Treatment temperature (F)	Hours at temperature prior to storage at 41F	Ethylene treatment (No/Yes)	Days to ripe	Shrivel (0-3)	Weight loss (%)	Peel Color (0-6)	Ripening uniformity (1-5)	Flesh to Seed (0-3)	Body rot (%)	Body rot severity (0.5 – 3)[z]	Stem end rot (%)	Stem end rot severity (0.5 – 3)[z]
41	*0*	-	*8.14*	*0.73*	*4.50*	*4.90*	*4.52*	*0.26*	*0.00*	-	*0.00*	-
68	24	No	7.27	0.71	4.73	5.00	4.50	0.34	2.68	0.20	5.12	0.30
68	48	No	7.76	0.95	4.87	5.14	4.54	0.35	5.34	0.80	5.32	0.35
68	*24*	*Yes*	*5.58*	*0.82*	*4.18*	*4.87*	*4.75*	*0.34*	*13.32*	*0.40*	*5.34*	*0.27*
68	*48*	*Yes*	*4.37*	*0.62*	*3.84*	*4.94*	*4.57*	*0.18*	*13.32*	*0.40*	*7.78*	*0.43*
77	24	No	8.09	0.96	5.10	5.00	4.59	0.27	3.80	0.30	2.68	0.30
77	48	No	7.50	1.06	5.01	5.13	4.47	0.29	2.66	0.10	5.34	0.40
77	*24*	*Yes*	*7.24*	*1.16*	*4.75*	*5.21*	*4.63*	*0.33*	*6.66*	*0.30*	*19.10*	*0.45*
77	*48*	*Yes*	*5.86*	*0.96*	*4.97*	*5.07*	*4.47*	*0.19*	*20.58*	*0.41*	*47.70*	*0.56*
86	24	No	8.67	1.21	5.33	4.98	4.44	0.31	1.34	0.10	2.46	0.20
86	48	No	7.60	1.01	5.79	4.89	4.49	0.31	0.00	-	2.68	0.30
86	*24*	*Yes*	*9.67*	*1.21*	*5.79*	*5.06*	*4.46*	*0.31*	*9.12*	*0.50*	*21.76*	*0.83*
86	*48*	*Yes*	*7.17*	*1.14*	*6.03*	*5.25*	*4.26*	*0.29*	*19.80*	*0.95*	*53.56*	*0.80*
95	24	No	8.71	1.12	5.50	4.87	4.46	0.35	10.46	0.53	4.68	0.20
95	48	No	7.96	1.10	6.66	4.89	4.40	0.28	9.34	0.58	10.22	0.80
95	*24*	*Yes*	*8.99*	*1.15*	*5.81*	*4.97*	*4.57*	*0.27*	*13.14*	*0.61*	*17.32*	*0.67*
95	*48*	*Yes*	*7.59*	*1.30*	*6.76*	*5.03*	*4.12*	*0.47*	*51.78*	*1.30*	*45.78*	*0.65*

[z] Stem end rot and body rot severity for decayed fruit only.

Table 3. Selected characteristics of ripe 'Hass' avocado following continuous holding at 68, 77, 86 or 95F for either 0 or 48 hours with or without ~40 ppm ethylene. Values reported are the average of data collected from fruit harvested February 25, April 8 and August 19, 2002 from Ventura County. Fruit harvested from the same group of trees each time. Following harvest, the fruit taken to UC-KAC and placed under postharvest treatment within 24 hours.

Ripening temperature (F)	Ethylene Treatment (hrs)	Days to ripe	Shrivel (0-3)	Weight loss (%)	Peel Color (0-6)	Ripening uniformity (1-5)	Flesh to Seed (0-3)	Body rot (%)	Body rot severity (0.5 – 3)[z]	Stem end rot (%)	Stem end rot severity (0.5 – 3)[z]
68	0	13.37	1.08	5.51	5.05	4.23	0.28	2.23	0.17	4.47	0.67
68	48	9.78	0.66	4.43	4.40	4.61	0.28	2.23	0.17	4.43	0.25
77	0	12.73	1.49	7.44	5.58	3.76	0.59	14.97	0.96	26.57	1.49
77	48	9.23	0.85	5.46	4.83	4.43	0.78	14.50	0.65	30.37	0.73
86	24	16.09	1.81	11.76	5.73	3.46	2.01	62.60	1.76	71.87	1.11
86	48	11.03	1.65	8.53	5.37	3.44	1.93	47.77	1.85	64.80	1.05
95	24	13.16	2.54	21.08	4.18	2.03	1.02	36.77	1.70	37.60	1.27
95	48	16.43	2.57	22.02	5.08	2.30	2.12	50.67	2.27	45.93	1.65

[z] Stem end rot and body rot severity for decayed fruit only.

Table 4. Effect of CO_2 concentration during ethylene treatment (48 hours at 68F) on 'Hass' avocado softening, as measured by the digital Firmometer (300g weight) 2 and 4 days after start of ethylene treatment, and days to fully ripe. Average values are shown and those followed by different letters in the same column are statistically significant.

Treatment		Firmometer value		
Ethylene (ppm)	CO_2 (%)	2 days	4 days	Days to ripe
0	0.5	15.9 a	21.7 a	8.1 d
100	0.5	28.9 d	88.5 d	4.7 ab
100	1.2	28.2 cd	91.6 d	4.6 a
100	2.4	27.0 cd	87.8 cd	4.7 ab
100	5	24.6 bc	76.6 bc	5.4 bc
100	10	22.4 b	68.7 b	5.6 c
LSD		4.09	11.47	0.70
P value		<0.001	<0.001	<0.001

Table 5. Effect of CO_2 concentration during ethylene treatment (48 hours at 20ºC (68°F)) on avocado peel color as measured by Minolta chromameter (L, chroma and Hue angle) and rated by eye, 2 and 4 days after start of ethylene treatment and when fully ripe. Average values are shown and those followed by different letters in the same column are statistically significant.

Treatment		2 days				4 days				Ripe
Ethylene (ppm)	CO_2 (%)	L	Chroma	Hue	Eye rating	L	Chroma	Hue	Eye rating	Eye rating
0	0.5	38.80c	12.50d	127.0c	1.9a	37.43b	11.07b	118.7b	2.3a	4.9a
100	0.5	36.58a	8.86a	116.7a	2.9c	33.29a	3.39a	49.9a	4.3b	5.1ab
100	1.2	36.47a	9.51ab	117.6a	2.6bc	33.05a	3.31a	48.0a	4.4b	5.1ab
100	2.4	36.92ab	10.95bcd	119.9ab	2.6bc	33.59a	4.10a	56.8a	4.1b	5.1ab
100	5	37.01ab	10.54abc	121.9b	2.4b	33.19a	3.53a	54.1a	4.3b	5.3b
100	10	37.58b	11.56cd	121.9b	2.4b	33.44a	3.98a	54.8a	4.2b	5.3b
LSD		0.713	1.886	3.97	0.27	0.681	1.170	18.27	0.33	0.24
P value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.003

Table 6. Effect of CO_2 concentration during ethylene treatment (48 hours at 68F) on incidence and severity of rots (stem end rots and body rots) and physiological disorders (uneven ripening in the flesh, measured by poking with a toothpick, and pink discoloration in the flesh). Fruit were assessed for quality when ripe (equivalent to a puncture value of 1lbf using an 8mm Effegi head or an average Firmometer value of 80 using a 200g 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 values are shown and those followed by different letters in the same column are statistically significant.

Treatment		Sound (% overall acceptable)	Incidence (%)				Severity (%)		
Ethylene (ppm)	CO_2 (%)		Stem End Rot	Body Rot	Tooth pick	Pink Flesh	Stem End Rot	Body Rot	Tooth pick
0	0.5	97.8	20.0 ab	6.7 ab	2.2	7.8 a	2.2	0	0
100	0.5	98.9	10.0 a	7.8 abc	1.1	25.6 b	1.1	0	0
100	1.2	96.7	13.3 ab	10.0 abc	1.1	27.8 b	0	1.1	0
100	2.4	98.9	7.8 a	3.3 a	1.1	24.4 ab	1.1	0	0
100	5	90.0	24.4 b	16.7 c	1.1	28.9 b	2.2	3.3	1.1
100	10	93.3	18.9 ab	14.4 bc	5.6	26.7 b	4.4	1.1	3.3
P value		ns	*	*	ns	*	ns	ns	ns

Figure 1. Distribution of ripening of 'Hass' avocado at 68F following a 48 hours ethylene treatment (100 ppm) and varying levels of carbon dioxide (CO_2).