Avocado Postharvest Quality

Continuing Project: Year 4 of 5

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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) and postharvest pathology (Smilanick, Margosan, Sievert) and Postharvest engineering and transit research (Thompson and Slaughter). Although Dr. Smilanick and Mr. Margosan are not currently funded they continue to assist us in pathogen identification when necessary.

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) Continue a collaborative study with A. Woolf and A. White to examine the effects of high temperature (>68ºF) 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

We conducted activities in all project objectives this year. We will discuss in detail results from the 2003 high temperature tests and provide a comparison of this year's results to the results summarized in 2002. Additionally, in February 2003 we were requested to evaluate the response of 'Hass' avocado to low dose x-ray irradiation. The results from this study are also presented. Below is a short synopsis of progress in other project objectives.

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 variety trials at both UC Lindcove Research and Extension Center in Exeter and the Richardson trial in Porterville 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'. Fruit of all varieties showed symptoms of internal chilling injury following 6 week storage at 41ºF (5ºC), however there were differences between cultivars, with 'Nobel' appearing slightly more susceptible to low temperatures.

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 provided decayed fruit for identification to Dr. Smilanick from our various experiments for identification. No unusual decay organisms were identified during this funding year.

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 plan to expand these studies during the upcoming season.

In addition, we are collaborating with J. Thompson (Agricultural Engineering, UC Davis) to evaluate alternative package designs to reduce injury to ripe avocado. A very preliminary evaluation of a packaging prototype was conducted in June 2003 with very promising results (Figure 1 shows damage to fruit packed in a "standard" tray).

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. A. White and A. Woolf have prepared updated versions of the Assessment Manual. The updated manual was presented to industry representatives and discussed for release within the US market. The response by industry representatives reviewing the draft was mixed, with some believing that a manual of "problems" would be detrimental to the California 'Hass' image.

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.

High temperature effects on 'Hass' fruit quality.

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 70ºF (21ºC).

In 2002 we conducted five tests to examine the influence of short duration high temperature exposures with or without ethylene on fruit ripening and storage quality. These results were summarized at the 2002 Research Symposium (Arpaia et al., 2002). Those results both supported and expanded research previously published by Eaks (1978) and Hopkirk et al. (1994). It

highlighted the importance of temperature management during the ethylene conditioning process and demonstrated that excessive pulp temperatures during ethylene conditioning can indeed negatively impact ripe fruit quality. For the current year we focused on two ripening temperatures, 68ºF (20ºC) and 77ºF (25ºC) and repeated some of the treatments from 2002 as well as adding 3 additional treatments.

All fruit were harvested from the same set of trees from either an orchard near Fillmore (Harvests 1 and 2) or an orchard near Somis (Harvests 3 – 5). Both sites are located 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 41ºF. 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 (~45 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). We completed fruit evaluation and data entry for the 2003 season in early October.

Table 1 reports the data from fruit that were immediately ripened following high temperature (+/- ethylene) exposure for both 2002 and 2003. The data shown here is the average for all tests (February – August in both years). As in 2002, we observed a trend for longer ripening times at 77ºF whether the fruit was treated with ethylene or not. 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 68ºF. In 2003 fruit treated with 48 hours of ethylene took an average of 1 day longer to ripen when the fruit had been treated at 77ºF.

The most striking influence of even a 24 hour exposure at 77ºF is the increased incidence of both stem end rot and body rots. This effect is greatest when comparing the ethylene treated fruit between temperatures (5 vs. 17% stem end rot with a 24 hour ethylene treatment; 3 vs. 18% stem end rot with a 48 hour ethylene treatment, respectively for 68ºF and 77ºF). The incidence of body rots was similarly affected. The incidence of stem end rot was reduced by ethylene treatment. This reduction is most likely related to the shortened ripening time (note "days to ripe").

Table 2 presents the same ripe fruit characteristics following 14 days of 41ºF 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 68ºF. What is interesting to note is the influence of holding the fruit at elevated temperature prior to storage. For instance, the incidence of stem end rot when the fruit is immediately cooled to 41ºF was 6.00% in 2003. If cooling was delayed either 24 or 48 hours (at

68ºF) the incidence of decay increased to 15.00 and 18.00% respectively. This increase is even greater if during the "delay" the fruit were exposed to ethylene (36.00 and 50.00% incidence, respectively). The same differences were detected for fruit held at 77ºF.

Table 3 compares the ripening characteristics of fruit either treated with ethylene prior to storage or following storage. A number of things can be noted. First, the average days to ripe is again extended when the fruit has been exposed to 77ºF. Secondly, even without an ethylene treatment, the ripening time is greatly reduced as compared prior to storage (Table 1, 13.93 days vs. 6.16 days). Ethylene treatment after storage results in decay levels comparable to the control fruit as compared to the fruit treated with ethylene prior to storage.

The results from this current year of research confirm our observations from 2002 and argue strongly for proper temperature management after harvest and during ethylene treatment. Improper temperature management during the ripening process can result in increased decay, increased ripening times and ultimately loss of consumer confidence.

Low dose x-ray irradiation effects on 'Hass' fruit quality.

The California avocado industry is vulnerable to exotic quarantine pests, especially a myriad of fruit fly species. Currently the only approved disinfestations treatments are methyl bromide fumigation or cold treatment. One of the newer approved quarantine treatments for fresh horticultural products is irradiation. Historically, it has been viewed that irradiation was not a viable quarantine option for fresh market avocado; however, recent technological advances challenge this perception. Notable changes that have occurred include the develop of x-ray and electron beam irradiators which allow for more controlled irradiation of product as compared to Cesium and Cobalt sources. Additionally, the older research on avocado used longer dwell times (minutes to hours) and had no control over treatment temperature. The "new" generation of irradiation technology allows for treatment times on the magnitude of seconds and allows for better temperature management. Finally, the major breakthrough in recent years has been the approval of sterilization doses for fruit flies rather than lethal doses. This means that the treatment dose for control is drastically reduced to a level which may not be injurious to avocado. This technology is being currently employed commercially for Hawaiian grown papaya, litchi and other tropical fruit crops which do not tolerate fumigation, heat or cold disinfestations treatments.

We were requested in early 2003 to evaluate the potential of low dose irradiation on 'Hass' fruit quality. This research was done in collaboration with Suresh DeCosta of the SureBeam Corporation. The fruit were irradiated at SureBeam facility in Vernon, CA (as of 9/30/03 this facility has been closed). Freshly harvested avocado from 3 grower lots were obtained from a Fallbrook packinghouse within 24 hours of harvest. Following packing the fruit were transported to Vernon (near Los Angeles) and irradiated within 12 hours of packing. The following doses were used: 0, 150, 300 and 450 GY (15, 30 or 45 krads). The fruit were held overnight at the irradiation facility at 41ºF (5ºC) then transported to the UC Kearney Ag Center the next day. The fruit were divided into 2 lots. One half of the fruit were ripened at 68F without storage. The remaining fruit were stored at 41ºF for 3 weeks. Each storage lot was further divided into half. One-half of the fruit received a 48 hour ethylene treatment (~50 ppm); the remaining fruit were ripened without ethylene.

The fruit were monitored daily as in the heat tests described above and evaluated when judged "ripe". In the case of the higher irradiation doses, some fruit failed to completely ripen. In this case, we used our "best" judgment on when to evaluate the fruit even though it had failed to completely ripen.

A summary of the results are presented in Tables 4 – 6 and Figure 2a – d. Evaluated parameters which did not yield statistical differences are not presented. From reviewing all tables it is evident that there was a highly significant effect of low dose irradiation on ripe fruit quality. This effect on fruit quality is more striking following storage at 41ºF.

Table 4 presents data on the response of 'Hass' avocado and the influence of irradiation on general ripening characteristics. Irradiation treatment regardless of the storage treatment prolonged the days to ripeness or at the higher doses inhibited ripening (see results for uneven ripening). We typically do not cut fruit for evaluation until the average firmness for an individual fruit is 1.5 lbf or lower, however, when it was evident that the irradiated fruit were not ripening in an normal fashion, a decision was made to evaluate partially ripe fruit (see results for average flesh firmness). Additionally irradiation changed the appearance of the flesh from "creamy" to "dry" (see results for flesh appearance). Many of the irradiated fruit, when cut had a distinct "off" odor which was objectionable (see results for % of fruit with odor).

Table 5 presents data on the response of 'Hass' avocado and the influence of irradiation on postharvest decay. Irradiation, regardless of dosage, increased the incidence of stem end rots, vascular streaking (which is related to stem end rot) and body rots. The percentage incidence of decay greatly increased in irradiated fruit following storage, whereas there was only a slight increase in the control fruit after storage. The severity of the decay was also greater in the irradiated fruit. When fruit were not stored, the severity of stem end rot and body rot of fruit irradiated at 150 GY did not differ from that of the control fruit, however, following storage, the severity of decay in this treatment was equivalent to that of fruit irradiated at either 300 or 450 GY.

Table 6 presents data on the response of 'Hass' avocado and the influence of irradiation on physiological disorders. Irradiated fruit had higher levels and greater severity of flesh discoloration, vascular discoloration in both storage treatments. Additionally, the irradiation treatment affected the peelability of the fruit. Irradiated fruit were consistently more difficult to peel following ripening.

The results of this test, in which freshly harvested unripe avocados were treated, indicate that x-ray irradiation is not a viable alternative to either methyl bromide fumigation or cold treatment as a postharvest fruit fly disinfestation treatment.

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Table 1. Selected characteristics of ripe 'Hass' avocado following holding at 68 or 77ºF for either 0, 24 or 48 hours with or without ~40 ppm ethylene prior to ripening at 68ºF. Values reported for 2002 are the average of data collected from fruit harvested February 25, April 8, May 21, July 8 and August 19, 2002 from Fillmore area of Ventura County. Values reported for 2003 are the average of data collected from fruit harvested February 3 April 7, June 9, June 30 and July 29, 2003 from Ventura County (Fruit from harvests 1-2 from Fillmore area; fruit from harvests 3-5 from Somis area). Fruit from each grower 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 temp. (ºF)	Hours at temperature prior to ripening at 68ºF	Ethylene treatment (No/Yes)	Flesh firmness after treatment (lbf)[z]	Days to ripe	Shrivel (0-3)	Weight loss (%)	Peel Color (0-6)	Ripening uniformity (1-5)	Body rot (%)	Body rot severity (0.5 – 3)[y]	Stem end rot (%)	Stem end rot severity (0.5 – 3)[y]
2001 – 02 Season												
68	0	No	-	13.93	1.25	5.19	4.94	4.33	6.68	0.20	17.36	0.80
68	24	Yes	-	8.69	0.64	3.81	4.53	4.73	2.68	0.20	4.00	0.45
68	48	Yes	-	6.14	0.44	2.80	4.34	4.87	0.00	-	1.34	0.10
77	*24*	*No*	-	*14.07*	*1.19*	*5.52*	*4.69*	*4.23*	*8.00*	*0.60*	*21.34*	*0.90*
77	*48*	*No*	-	*14.41*	*1.42*	*5.49*	*4.84*	*4.30*	*13.32*	*0.60*	*26.68*	*0.90*
77	*24*	*Yes*	-	*10.87*	*1.03*	*4.65*	*4.78*	*4.57*	*9.32*	*0.45*	*14.68*	*0.63*
77	*48*	*Yes*	-	*7.86*	*0.72*	*3.77*	*4.75*	*4.20*	*8.00*	*0.25*	*6.66*	*0.30*
2002 – 03 Season												
68	0	No	46.26	13.41	0.89	4.38	4.20	4.47	13.00	0.72	35.00	0.82
68	24	Yes	43.48	8.34	0.64	3.48	4.11	4.60	2.00	0.50	5.00	1.17
68	48	Yes	30.15	6.40	0.63	2.92	4.09	4.63	0.00	-	3.00	0.75
77	*24*	*No*	*46.08*	*13.45*	*0.88*	*4.49*	*4.33*	*4.52*	*8.00*	*0.63*	*29.00*	*0.98*
77	*48*	*No*	*45.31*	*13.58*	*0.98*	*4.57*	*4.18*	*4.47*	*8.00*	*0.72*	*34.00*	*0.84*
77	*24*	*Yes*	*44.44*	*9.33*	*0.75*	*3.77*	*4.27*	*4.48*	*9.00*	*0.56*	*17.00*	*1.07*
77	*48*	*Yes*	*27.59*	*7.59*	*0.83*	*3.42*	*4.62*	*4.42*	*8.00*	*0.58*	*18.00*	*0.67*

[z] Flesh firmness after treatment not monitored in 2002.
[y] Stem end rot and body rot severity for decayed fruit only.

Table 2. Selected characteristics of ripe 'Hass' avocado following holding at 68, or 77ºF for either 0, 24 or 48 hours with or without ~40 ppm ethylene prior to 14 days storage at 41ºF. Fruit ripened at 68F following storage. Values reported for 2002 are the average of data collected from fruit harvested February 25, April 8, May 21, July 8 and August 19, 2002 from Fillmore area of Ventura County. Values reported for 2003 are the average of data collected from fruit harvested February 3 April 7, June 9, June 30 and July 29, 2003 from Ventura County (Fruit from harvests 1-2 from Fillmore area; fruit from harvests 3-5 from Somis area). Fruit from each grower 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 temp. (ºF)	Hours at temperature prior to 41ºF	Ethylene treatment (No/Yes)	Flesh firmness after treatment (lbf)[z]	Days to ripe	Shrivel (0-3)	Weight loss (%)	Peel Color (0-6)	Ripening uniformity (1-5)	Body rot (%)	Body rot severity (0.5 – 3)[y]	Stem end rot (%)	Stem end rot severity (0.5 – 3)[y]
2001 – 02 Season												
41	*0*	*-*	*-*	*8.14*	*0.73*	*4.50*	*4.90*	*4.52*	*0.00*	*-*	*0.00*	*-*
68	24	No	-	7.27	0.71	4.73	5.00	4.50	2.68	0.20	5.12	0.30
68	48	No	-	7.76	0.95	4.87	5.14	4.54	5.34	0.80	5.32	0.35
68	*24*	*Yes*	*-*	*5.58*	*0.82*	*4.18*	*4.87*	*4.75*	*13.32*	*0.40*	*5.34*	*0.27*
68	*48*	*Yes*	*-*	*4.37*	*0.62*	*3.84*	*4.94*	*4.57*	*13.32*	*0.40*	*7.78*	*0.43*
77	24	No	-	8.09	0.96	5.10	5.00	4.59	3.80	0.30	2.68	0.30
77	48	No	-	7.50	1.06	5.01	5.13	4.47	2.66	0.10	5.34	0.40
77	*24*	*Yes*	*-*	*7.24*	*1.16*	*4.75*	*5.21*	*4.63*	*6.66*	*0.30*	*19.10*	*0.45*
77	*48*	*Yes*	*-*	*5.86*	*0.96*	*4.97*	*5.07*	*4.47*	*20.58*	*0.41*	*47.70*	*0.56*
2002 – 03 Season												
41	*0*	*-*	*46.06*	*6.16*	*0.49*	*3.89*	*4.97*	*4.67*	*1.00*	*0.50*	*6.00*	*0.83*
68	24	No	42.16	5.96	0.61	3.95	5.04	4.75	3.00	0.83	15.00	0.59
68	48	No	42.99	5.60	0.67	3.84	5.05	4.76	3.00	0.50	18.00	0.78
68	*24*	*Yes*	*31.61*	*5.19*	*0.63*	*3.58*	*4.61*	*4.85*	*9.00*	*1.15*	*36.00*	*0.81*
68	*48*	*Yes*	*9.19*	*4.86*	*0.60*	*3.97*	*4.53*	*4.67*	*19.00*	*1.30*	*50.00*	*1.13*
77	24	No	39.24	5.67	0.80	3.80	4.55	4.68	4.00	0.50	10.00	0.54
77	48	No	43.20	5.44	0.77	4.02	4.82	4.73	4.00	0.83	28.00	0.84
77	*24*	*Yes*	*33.88*	*5.55*	*0.73*	*3.96*	*4.45*	*4.69*	*1.00*	*1.00*	*42.00*	*0.89*
77	*48*	*Yes*	*10.15*	*5.70*	*0.89*	*4.53*	*4.64*	*4.49*	*28.00*	*0.87*	*50.00*	*1.08*

[z] Flesh firmness after treatment not monitored in 2002.

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

Table 3. Selected characteristics of ripe 'Hass' avocado following 14 days storage at 41ºF and ripening at 68ºF. Fruit were treated for 24 hours of ethylene (~45 ppm) either before or after storage. Fruit ethylene treated at either 68 or 77ºF. Values reported are the average of data collected from fruit harvested February 3 April 7, June 9, June 30 and July 29, 2003 from Ventura County (Fruit from harvests 1-2 from Fillmore area; fruit from harvests 3-5 from Somis area). Fruit from each grower 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 temp. (ºF)	Hours at temperature prior to ripening at 68ºF	Ethylene treatment before or after storage	Flesh firmness after treatment (lbf)	Days to ripe	Shrivel (0-3)	Weight loss (%)	Peel Color (0-6)	Ripening uniformity (1-5)	Body rot (%)	Body rot severity (0.5 – 3)[z]	Stem end rot (%)	Stem end rot severity (0.5 – 3)[z]
68	0	-	46.06	6.16	0.49	3.89	4.97	4.67	1.00	0.50	6.00	0.83
68	*24*	*Before*	*31.61*	*5.19*	*0.63*	*3.58*	*4.61*	*4.85*	*9.00*	*1.15*	*36.00*	*0.81*
68	*24*	*After*	*29.70*	*5.79*	*0.41*	*3.59*	*4.99*	*4.79*	*1.00*	*1.00*	*9.00*	*0.63*
77	24	Before	33.88	5.55	0.73	3.96	4.45	4.69	1.00	1.00	42.00	0.89
77	24	After	19.09	6.62	0.70	4.02	5.21	4.66	2.00	0.50	13.00	0.82

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

Table 4. The response of 'Hass' avocado to low dose irradiation from an x-ray source – the influence on general ripening characteristics.

	% weight loss	Days to ripe	Shrivel (0 - 3)	Average flesh firmness when cut	% of fruit with odor	Flesh appearance (1-3)	Uneven Ripening	
							% incidence	% moderate or severe
NO Storage								
0 GY	4.63	7.94	1.50	1.11	0.69	1.88	2.08	0.00
150 GY	4.42	7.76	1.21	1.23	3.47	2.09	10.42	0.00
300 GY	6.42	10.15	1.61	1.56	36.81	2.58	61.81	15.97
450 GY	7.13	12.09	1.65	2.05	49.31	2.71	86.81	46.53
Ethylene Yes	5.97	9.70	1.57	1.51	25.35	2.39	47.22	18.40
Ethylene No	5.33	9.27	1.42	1.47	19.79	2.24	33.33	12.85
GY	0.001	0.001	ns	0.001	0.001	0.001	0.001	0.001
Ethylene	0.05	ns	ns	ns	ns	0.05	0.01	ns
Interaction	ns	0.05	ns	ns	ns	ns	ns	ns
3 weeks at 41°F (5°C)								
0 GY	4.62	3.39	1.26	1.28	0.00	1.82	11.81	0.00
150 GY	9.62	11.41	1.46	1.44	70.14	2.68	66.67	25.00
300 GY	10.80	11.65	1.63	2.24	83.33	2.97	91.67	41.67
450 GY	10.91	11.85	2.02	2.53	90.28	2.98	92.36	40.28
Ethylene Yes	9.05	9.67	1.58	1.96	58.68	2.62	64.93	24.31
Ethylene No	8.93	9.48	1.60	1.79	63.19	2.61	66.32	29.17
GY	0.001	0.001	0.01	0.001	0.001	0.001	0.001	0.001
Ethylene	ns	ns	ns	ns	ns	ns	ns	ns
Interaction	ns	ns	ns	ns	ns	ns	ns	ns

Fruit procured from commercial packinghouse in February 2003 and irradiated within 48 hours of harvest at the Surebeam Corporation Facility in Vernon, CA. Fruit stored, ripened and evaluated at the UC Kearney Agricultural Center in Parlier, CA. Values are the average of 3 grower lots; 24 fruit per grower lot per treatment combination. Fruit treated with ~50 ppm ethylene following storage.

Shrivel – Fruit rated when ripe as having no shrivel (0); slight shriveling (1); moderate shriveling (2) or severe shriveling (3).

Odor – Fruit rated as having an "off" odor when cut.

Flesh appearance – Cut fruit rated when ripe as being watery (1); creamy (2); or dry (3) in appearance.

Uneven ripening – Cut fruit judged to have uneven ripening; fruit rated as completely uniform (5); slight differences in ripening uniformity within fruit (4); distinct areas in fruit where flesh softening is moderately firmer (3); distinct areas in fruit where flesh softening is partially unripe (2); distinct areas in fruit where flesh is not ripe as compared (1).

Table 5. The response of 'Hass' avocado to low dose irradiation from an x-ray source – the influence on the incidence and severity of postharvest decay.

	Stem End Rot		Vascular Streaking from Stem End		Body Rot	
	% incidence	% moderate or severe	% incidence	% moderate or severe	% incidence	% moderate or severe
NO Storage						
0 GY	1.39	0.00	6.25	0.00	1.39	0.00
150 GY	4.17	1.39	96.53	33.33	6.94	1.39
300 GY	16.67	6.25	100.00	85.42	48.61	27.78
450 GY	28.47	13.19	99.31	69.44	59.03	32.64
Ethylene Yes	12.85	4.51	75.35	47.57	33.33	18.75
Ethylene No	12.50	5.90	75.69	46.53	24.65	12.15
GY	0.05	ns	0.001	0.001	0.001	0.001
Ethylene	ns	ns	ns	ns	ns	ns
Interaction	ns	ns	ns	ns	ns	ns
3 weeks at 41°F (5°C)						
0 GY	3.47	0.69	13.19	3.47	5.56	2.78
150 GY	75.69	44.44	100.00	87.50	72.22	45.14
300 GY	75.69	45.14	100.00	84.72	68.75	33.33
450 GY	77.78	37.50	100.00	94.44	72.22	42.36
Ethylene Yes	58.33	29.17	77.08	67.71	53.82	27.08
Ethylene No	57.99	34.72	79.51	67.36	55.56	34.72
GY	0.001	0.001	0.001	0.001	0.001	0.05
Ethylene	ns	ns	ns	ns	ns	ns
Interaction	ns	ns	ns	ns	ns	ns

Fruit procured from commercial packinghouse in February 2003 and irradiated within 48 hours of harvest at the Surebeam Corporation Facility in Vernon, CA. Fruit stored, ripened and evaluated at the UC Kearney Agricultural Center in Parlier, CA. Values are the average of 3 grower lots; 24 fruit per grower lot per treatment combination. Fruit treated with ~50 ppm ethylene following storage.
Fruit rated on a 0 to 3 scale where 0 = none; 1 = slight; 2 = moderate (> 20% of surface area affected); 3 = severe.

Table 6. The response of 'Hass' avocado to low dose irradiation from an x-ray source – the influence on the incidence and severity of physiological disorders.

	Flesh Discoloration		Vascular Discoloration		Ease of Peeling	
	% incidence	% moderate or severe	% incidence	% moderate or severe	% incidence	% moderate or severe
NO Storage						
0 GY	0.69	0.00	2.78	0.00	5.56	0.00
150 GY	2.08	0.00	95.14	29.86	61.11	25.69
300 GY	48.61	27.08	100.00	81.94	84.72	52.78
450 GY	86.11	52.08	99.31	66.67	95.14	61.11
Ethylene Yes	37.85	22.22	73.96	45.49	67.71	40.28
Ethylene No	30.90	17.36	74.65	43.75	55.56	29.51
GY	0.001	0.001	0.001	0.001	0.001	0.001
Ethylene	ns	ns	ns	ns	ns	0.05
Interaction	ns	ns	ns	ns	ns	ns
3 weeks at 41°F (5°C)						
0 GY	4.86	0.00	10.42	0.00	36.81	5.56
150 GY	90.28	75.00	99.31	90.97	84.03	68.06
300 GY	100.00	93.75	100.00	95.83	99.31	93.06
450 GY	100.00	99.31	100.00	99.31	100.00	99.31
Ethylene Yes	73.26	65.63	77.08	71.18	77.43	64.93
Ethylene No	74.31	68.40	77.78	71.88	82.64	68.06
GY	0.001	0.001	0.001	0.001	0.001	0.001
Ethylene	ns	ns	ns	ns	ns	ns
Interaction	ns	ns	ns	ns	ns	ns

Fruit procured from commercial packinghouse in February 2003 and irradiated within 48 hours of harvest at the Surebeam Corporation Facility in Vernon, CA. Fruit stored, ripened and evaluated at the UC Kearney Agricultural Center in Parlier, CA. Values are the average of 3 grower lots; 24 fruit per grower lot per treatment combination. Fruit treated with ~50 ppm ethylene following storage.
Fruit rated on a 0 to 3 scale where 0 = none; 1 = slight; 2 = moderate (> 20% of surface area affected); 3 = severe.

Figure 1. Examples of damage to partially ripe 'Hass' avocado (tray pack) following simulated cross-country transport. Test conducted at the Weyerhauser Research Facility in Walnut Creek, CA in collaboration with Jim Thompson and David Slaughter from UC, Davis. Test conducted June, 2003.

Figure 2. ‘Hass’ avocado following low dose x-ray irradiation, 3 weeks storage at 41ºF (5ºC) and ripening at 68ºF (20ºC). (a) Fruit showing vascular discoloration and streaking; (b) fruit showing uneven ripening, flesh dryness and flesh discoloration; (c) fruit showing severe flesh drying and flesh discoloration; (d) side view of fruit showing flesh adhesion to seed following ripening and flesh discoloration.

a.

b.

c.

d.