HortScience 44(6):1655–1661. 2009.

Variation in 'Sharwil' Avocado Maturity during the Harvest Season and Resistance to Fruit Fly Infestation

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Additional index words. dry matter, maturity, oil content, *Persia americana*, postharvest, quality

Abstract. **Avocados cannot be exported from Hawaii to the continental United States without a quarantine treatment to prevent the spread of fruit flies. Research was conducted on the maturity and infestation potential of 'Sharwil' avocados to assist in development of a multicomponent systems approach for quarantine security. Changes in fruit dry matter content and oil content were determined throughout the harvest season for 'Sharwil' avocados grown at three orchard elevations over two production seasons. Also, the ability to infest fruit with Mediterranean fruit fly and oriental fruit fly was measured throughout the harvest season and during fruit ripening. Fruit quality was consistent from one year to the next, regardless of orchard elevation, however, the time of harvest within a production season impacted avocado quality. Late season fruit had higher dry matter and oil contents, were smaller in size, and had a shorter shelf life than early and midseason fruit, but fruit flavor and texture did not change throughout the season. Mean dry matter content ranged from 32% (30 Jan.) to 38% (24 Apr.) in 2007 and from 29% (8 Jan.) to 40% (29 Apr.) in 2008. Percentage of oil content ranged from 21% to 25% in 2007 and from 18% to 28% in 2008. 'Sharwil' fruit with a minimum mean oil content of 18% had 29% dry matter and acceptable sensory quality. The dry matter and oil contents of individual avocados were highly correlated (r = 0.97). Avocado was a poor fruit fly host immediately after harvest but became an increasingly favorable host as fruit ripened. Fruit fly infestation rates were similar among early, mid- and late season fruit. The results could be used to develop a maturity standard for 'Sharwil' avocados based on dry matter content at harvest, and to develop guidelines for postharvest practices of a systems approach for quarantine security.**

Avocados (*Persea americana* Mill.) are nutrient-dense fruits, high in unsaturated fats, fiber, niacin, folate, lutein, potassium, iron, and vitamins B_6, C, E, and K (USDA-ARS, 2008). The oil quality is beneficial to cardiovascular health, with about 65% to 75% monounsaturated fatty acids (oleic and palmitoleic) and 10% to 15% polyunsaturated fatty acids (linoleic) (Ozdemir and Topuz, 2004). Total oil content may exceed 30%, depending on cultivar and maturity (Woolf et al., 2004).

The avocado was introduced to the Hawaiian Islands in the early nineteenth century (Yee, 1957). Today, avocados are a small, yet important, component of Hawaii's diversified agriculture. The 'Sharwil' cultivar accounts for the majority of commercial avocado production in the state. This cultivar originated in Australia as a hybrid between the Guatemalan and Mexican horticultural races of avocado (Schnell et al., 2003). The trees bear pear-shaped fruit (≈250–550 g), with green rough skin, small seeds, and greenish yellow flesh of a buttery texture (Yee, 1957). The 'Sharwil' is often considered a gourmet avocado because it has a rich, nutty flavor.

Determining harvest maturity for 'Sharwil' fruit can be difficult. If harvested immature, the fruit typically shrivel in storage, ripen abnormally, and have poor eating quality. For cultivars such as 'Hass', the skin color changes from green to dark-green to purple or black with increasing maturity or ripening (Cox et al., 2004). However, the green skin of the 'Sharwil' cultivar does not darken with maturity, making it difficult to distinguish mature fruit from immature fruit. Subjective maturity indicators for 'Sharwil' fruit may include fruit size, a lack of skin glossiness, and a yellowish tint near the stem end.

Oil content forms the basis of maturity standards designed to ensure that only fully mature avocados are marketed. Oil content is a key component of avocado flavor and texture. The Hawaii Department of Agriculture specifies a minimum of 12% oil content for "Hawaii Fancy" and "Hawaii No. 1" grades, however, avocado cultivars are not specified (HDOA, 1986). Avocado cultivars vary widely in fruit oil content, from 5% to >30% (Woolf et al., 2004). 'Sharwil' fruit may contain an oil content significantly higher than 12%, and fruit harvested at this level may be immature, with a watery taste and rubbery texture.

Avocado oil content is highly correlated to fruit dry matter content (Lee et al., 1983). As fruit mature, the percentage of dry matter increases, as does the oil content; however, there is cultivar-to-cultivar variation in this relationship. Percentage of dry matter content has become the predominant maturity index for avocado harvesting, but it must be cultivar-specific (Bower and Cutting, 1988; Hofman et al., 2002; Lee et al., 1983). California and Australia use percentage of dry matter content as an indirect measure to determine oil content, and hence maturity, for different cultivars (Lee and Coggins, 1982; Woolf et al., 2004).

Currently, Hawaii-grown avocados are marketed and consumed locally, but growers would like to export 'Sharwil' fruit to the American mainland. Avocados cannot be exported from Hawaii to the mainland United States without a quarantine treatment to prevent the spread of Mediterranean fruit fly (*Ceratitis capitata*) and oriental fruit fly (*Bactrocera dorsalis*). However, the approved quarantine treatments (methyl bromide and cold treatments) degrade fruit quality and are not used (Nishijima et al., 1995). Avocado is generally considered to be a poor host for tephritid fruit flies (Aluja et al., 2004), but fruit become increasingly favorable hosts after harvest as they ripen and soften (Armstrong et al., 1983; Oi and Mau, 1989). At one time, 'Sharwil' avocado was believed to be resistant to fruit fly infestation when harvested at the hard, mature green stage and was approved for export as a nonhost under

Received for publication 20 Apr. 2009. Accepted for publication 13 Aug. 2009.
We thank Pat Sinclair for coordinating avocado harvests, and Steve Brown, Sandra Silva, Suzanne Sanxter, and Karen Wessel for excellent technical support.
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certain conditions (Armstrong, 1991). However, the nonhost status was rescinded after it was found that mature green fruit on the tree are occasionally infested, particularly by oriental fruit fly (Liquido et al., 1995). The predisposing factors are not understood but may be related to stress-induced ripening on the tree (Liquido et al., 1995; Follett, 2009). There is interest in exporting 'Sharwil' avocados to the American mainland markets under a systems approach to quarantine security based on the poor host status of the fruit, low prevalence of fruit flies in the orchard, shipment of mature green fruit, limited distribution, and postharvest safeguards (Jang, 1996). Determining the period of resistance to infestation after harvest is an important element to the systems approach.

Information on the maturity and susceptibility to fruit fly infestation of 'Sharwil' avocados could be used by USDA's Animal Plant Health Inspection Service (APHIS) in developing parameters of a systems approach for export. Our objectives were to determine fruit dry matter and oil contents throughout the harvest season and at different orchard elevations over two growing seasons. The results could be used to develop a maturity standard for 'Sharwil' avocados based on dry matter content at harvest. We also determined the ability to infest fruit with Mediterranean fruit fly and oriental fruit fly throughout the harvest season and during fruit ripening.

Materials and Methods

Fruit harvests. Mature-green 'Sharwil' avocados were harvested by growers from commercial orchards in the South Kona district of Hawaii Island every 2 weeks from January through April in 2007 and 2008. There were seven harvests in 2007 and nine harvests in 2008. The 'Sharwil' fruit were grower-defined as mature-green if they were dark green and hard (not yielding to pressure when squeezed firmly by hand), with pedicels attached and no surface blemishes. The fruit were randomly sampled from the same orchard blocks throughout a season. The orchards were located at three elevations: 427, 540, and 610 m. Fruit were sampled from three orchards in 2007 and from two orchards (427 and 540 m) in 2008. Twenty-five fruit from each site were transported to Hilo, HI, for insect infestation studies on the morning of harvest, and 40 fruit from each site were air-shipped to Honolulu for fruit quality analyses. Measurements and samples were taken on the same day of fruit arrival.

Fruit color and firmness. The fruit (40) from each site were labeled, randomly numbered, and weighed. External color readings were taken with a Konica Minolta chromameter (model CR-400; Minolta Corp., Ramsey, NJ). Two measurements were taken on opposite sides of each fruit. The fruit numbered one to 20 were evaluated immediately. The fruit were cut in half longitudinally and internal color readings were taken on both halves. Firmness was measured as Newtons (N) on intact fruit (with skin) using an Imada digital force gauge with a 10 mm chisel tip (Imada, Inc., Northbrook, IL).

Dry matter analysis. Individual fruit were sliced, peeled, and chopped in a small blender at high speed for 30 s. Samples (20 g) were dried for 48 h at 70 °C (until constant weight) and were then reweighed for percentage of dry matter determination. The dry avocado samples were stored in Ziplock® bags and shipped to the U.S. Department of Agriculture-Agricultural Research Service in Hilo for oil analysis.

Oil content. The oil content for each dry avocado sample was determined using an ANKOM Xt10 extraction system (ANKOM Technology, Macedon, NY). Dried, finely ground samples (1 g) were placed into sample bags and further dried for 3 h at 100 °C in an oven. Samples were weighed and placed into the extractor with 200 mL of petroleum ether and were extracted for 40 min. After extraction, samples were dried for 30 min at 100 °C, reweighed, and percentage of oil content was calculated.

Ripe fruit quality. The fruit numbered 21 to 40 were ripened at 22 °C (without exogenous ethylene) and inspected daily at the University of Hawaii, Honolulu. Fruit softening was used as an indicator of ripening. The fruit yielded to light finger pressure when gently squeezed and were considered ripe when the firmness was ≤10 N. The number of days from harvest to edible softness of a fruit stored at 22 °C was calculated as the shelf life. The final weight, external color, internal color, and firmness were taken when fruit were ripe. Slices of avocado were tasted and rated for flavor and texture by a sensory panel. Avocado taste and texture were scored on a scale from one (least favorable) to nine (most favorable). The sensory panel consisted of from four to 10 trained persons, the number depending upon availability and when the individual fruit were ripe and ready for evaluation. The smaller numbers occurred on the weekends.

Fruit fly infestation studies. In 2007, fruit from each harvest were exposed to gravid female Mediterranean fruit flies and oriental fruit flies to determine infestation levels and susceptibility to infestation. On each of six collection dates ranging from early to late during the harvest season, 25 mature green fruit from each of three sites were harvested and held for emergence of any fruit flies. On each collection date, six additional fruit were collected at each site for forced infestation studies. Three fruit were placed in a 25- × 25- × 25-cm screen cage with 10 gravid Medfly females or 10 gravid oriental fruit flies for 12 h. Fruit were then removed and held in 3.8-L plastic buckets with screened lids for 2 weeks for emergence. About 300 g of sand was added to the bucket as a pupation medium.

In 2008, fruit collections were made during the early (January), middle (April), and late (May) part of the harvest season. On each harvest date, mature green fruit were brought to the laboratory and held at 21 °C. On each day for 7 d, four fruit were placed in a 25- × 25- × 25-cm cage with 25 gravid females for 24 h. Four replicate cages were set up for Mediterranean fruit fly and oriental fruit fly on each day. After 24 h, fruit were removed from each cage and placed in a 3.8-L plastic bucket with a screened lid and sand and held at 20 to 25 °C. After 2 weeks, fruit and sand were inspected for pupae. Pupae were transferred to 120-mL plastic cups for adult emergence. Ripe papayas, which are a preferred fruit fly host, were exposed similarly during all tests as controls to demonstrate oviposition competence.

Data analysis. Data were subjected to analysis of variance using the general linear models (GLM) procedure for a two-factor design (SAS Institute, 2008). Data for each year were analyzed separately. After checking for homogeneity of variance, a combined analysis was completed for those variables where differences between years were not significant. Data were presented as means ± standard errors (SE), and where appropriate, means were separated using the Waller–Duncan k-ratio *t* test. Correlations between variables measured on mature green fruit at harvest (fruit weight, initial firmness, dry matter content, and oil content) were determined using individual fruit data (no. 1–20). Similarly, correlations between variables measured on ripe fruit (days to ripen, taste, and texture) were applied to individual fruit data (no. 21–40). However, correlations between variables measured at harvest and variables measured after ripening were determined using mean data for each site and harvest time per year. Regression analysis

Table 1. Fruit characteristics at harvest for the 'Sharwil' avocado cultivar grown in South Kona, HI.

Attribute		Mean[z]	Minimum	Maximum	*n*
Weight (g)		264.71 ± 2.08	163.20	501.10	1336
Initial firmness (N)		202.46 ± 1.07	164.96	246.13	551
Dry matter (%)		34.17 ± 0.18	21.91	46.78	554
Oil content (%)[y]		22.31 ± 0.16	11.88	32.62	553
Days to ripen		8.14 ± 0.07	3.00	13.00	652
Initial skin color[x]	L*	33.56 ± 0.05	28.46	64.06	1305
	C*	16.22 ± 0.08	7.85	28.91	1305
	H°	120.08 ± 0.08	98.40	127.30	1305
Initial flesh color[x]	L*	83.57 ± 0.05	76.96	87.39	626
	C*	47.10 ± 0.13	36.72	55.93	626
	H°	98.89 ± 0.07	93.50	106.18	626

[z]The values are the averages (±SE) of 551 to 1336 fruit harvested in 2007 and 2008.
[y]Percentage of oil content is expressed on a fresh weight basis.
[x]Surface color values are lightness (L*), chroma (C*), and hue angle (H°).

was used to predict percentage of oil content from dry matter content.

Results and Discussion

Fruit characteristics for 'Sharwil' avocado. Data analyzed over two production seasons revealed the average fruit characteristics for the 'Sharwil' avocado, as well as the range of variation that typifies this cultivar (Table 1). At harvest, the sampled fruit weighed an average of 265 g and were dark green and firm (203 N), with a vivid greenish-yellow flesh. Mean dry matter content was 34.17% and ranged from 21.91% to 46.78%. This is similar to the mean (35.5%) and range (25.4% to 43.6%) reported for the 'Hass' cultivar (Clark et al., 2007). The 'Sharwil' avocado typically had a high oil content, averaging 22.31% of its fresh weight. The average shelf life for individual fruit was 8 d at 22 °C, but ranged from 3 to 13 d. The results show the degree of fruit-to-fruit variation in maturity during the course of the study, and suggest that a method is needed to exclude immature or overmature fruit from commercial harvests.

Orchard elevation effects on avocado quality. Overall, orchard elevation had a minor effect on the ripening characteristics of

Table 2. Fruit quality of 'Sharwil' avocados harvested from orchards located at different elevations in South Kona, HI.

							Sensory attributes[y]	
Year	Orchard	Fruit wt (g)	Firmness (N)	Dry matter (%)	Oil content[z] (%)	Days to ripen	Flavor	Texture
2007	1 (427 m)	241.7 b[x]	186.9 b	35.58 a	23.21 a	8.1 b	6.17 a	6.59 a
	2 (540 m)	244.6 b	193.4 a	33.31 b	21.93 b	8.3 b	5.85 b	6.31 b
	3 (610 m)	276.3 a	193.3 a	32.88 b	21.63 b	9.2 a	5.74 b	6.32 b
2008	1 (427 m)	264.7 b	206.9 b	35.14 a	23.10 a	7.7 a	6.04 a	6.35 a
	2 (540 m)	275.7 a	217.7 a	33.07 b	21.24 b	7.9 a	5.80 a	6.05 b

[z]Percentage of oil content is expressed on a fresh weight basis.
[y]Sensory attributes were rated on ripe fruit on a scale from 1 (least favorable) to 9 (most favorable).
[x]The values are the averages of fruit harvested from Jan. through Apr. 2007 and 2008. Fruit weight, firmness, dry matter, and oil content were measured at harvest. Means within columns followed by the same letter were not significantly different by Waller–Duncan k-ratio *t* test at $P < 0.05$.

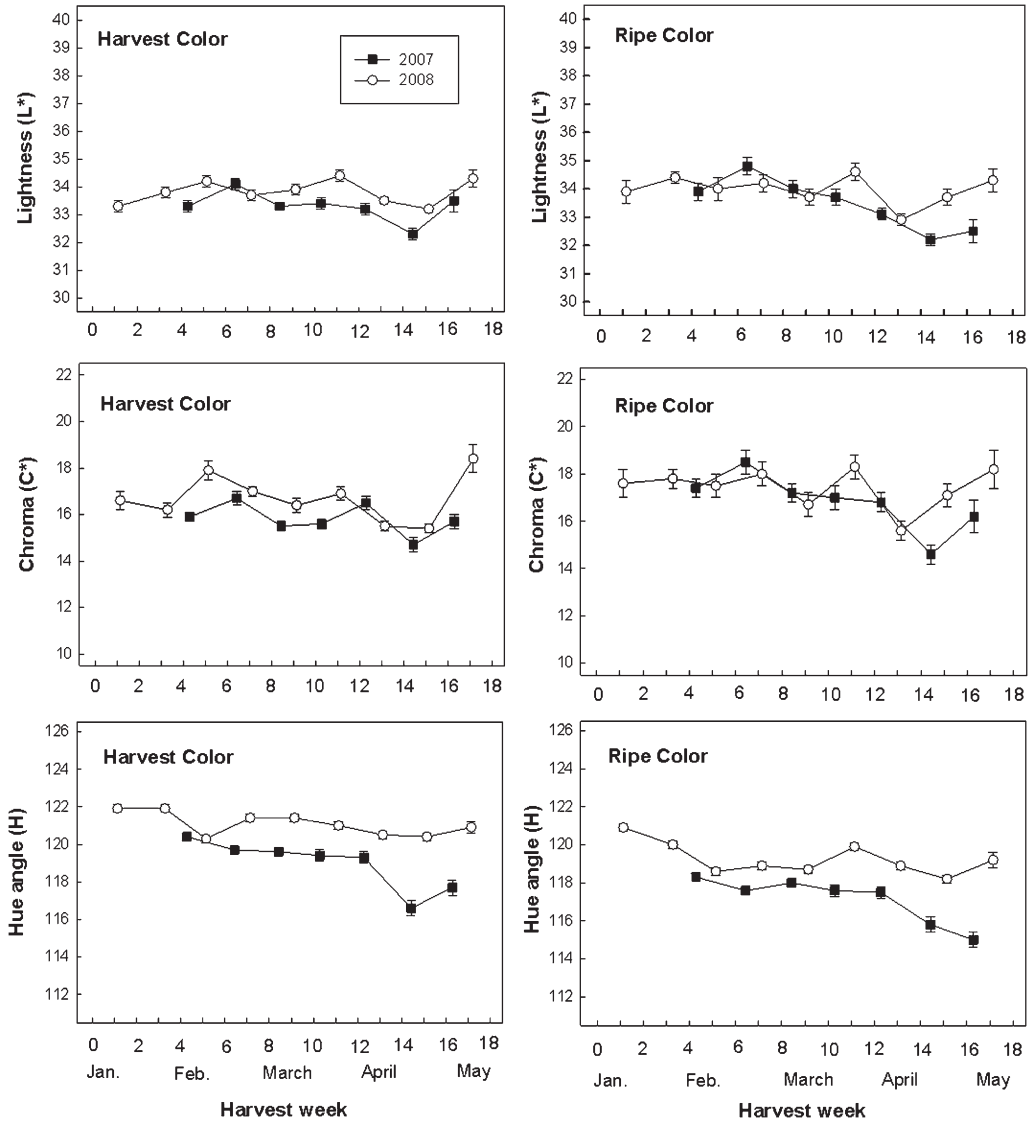

Fig. 1. Skin color of 'Sharwil' avocados on the day of harvest and after ripening at 22 °C when harvested at different times throughout the growing season.

'Sharwil' avocado, although the cooler microclimate (≈1 °C average difference) at higher elevations appeared to delay maturation. In 2007, fruit harvested from the high-elevation orchard (site 3, 610 m) were larger and ripened slower than fruit grown at lower elevations (site 1, 427 m and site 2, 540 m) (Table 2). Fruit grown at orchards 2 and 3 were firmer at harvest, with lower percentage of dry matter and oil content than avocados from the orchard at the lowest elevation. In 2008, avocados harvested from site 2 were larger and firmer, but had lower dry matter content and oil content than fruit harvested from site 1. In both years, fruit flavor and texture scores were slightly lower at the higher elevation orchards, following a similar trend for dry matter and oil content. However, there were no significant differences in the percentage of oil content, texture, and flavor of avocados harvested from different elevations at the same time. In general, avocados had slightly darker green skin color and a brighter yellow flesh color when grown at lower elevations (sites 1 and 2; data not shown). Also, the low-elevation orchard produced smaller fruit and had a longer production season than higher elevation orchards. However, orchard factors other than elevation (such as soil type or cultural practices) could have contributed to any differences observed among locations, and harvests from more orchards are needed to fully explore the microclimate effect on fruit maturation and ripening.

Changes in fruit color, weight, and firmness throughout the harvest season. The skin color of mature green avocados remained fairly stable as the harvest season progressed (Fig. 1), although external color (hue) was negatively correlated with harvest time ($r = –0.31$; $P < 0.001$) (Table 3). Ripe fruit skin color turned a lighter green as the fruit stayed on the tree longer (Fig. 1). Ripe avocados also had a bright yellow flesh color that was more vivid in late season fruit (data not shown).

In 2007, average fruit weight fluctuated between 246 to 276 g for avocados harvested from 30 Jan. to 27 Mar., and then decreased significantly (<217 g) in April (Fig. 2A). Fruit weight was generally higher in 2008 and peaked (300 g) on 8 Jan. and 19 Feb. harvests, whereas the smallest fruit (220 g) were harvested on 15 Apr. Fruit weight was positively correlated with skin color (hue) of mature fruit, indicating that large fruit were greener than small fruit (Table 3).

There was a significant negative correlation ($r = –0.40$; $P < 0.0001$) between fruit weight and harvest time (Table 3). This trend may have resulted from growers picking larger fruit (considered mature) earlier in the season, while delaying harvests of the smallest fruit until late season. This did not appear to adversely impact other quality characteristics, even for smaller fruit. Oil and dry matter contents actually increased in later harvests, and fruit flavor and texture did not change.

There were small differences in avocado firmness among harvest times in 2007, ranging from 204 N on 13 Mar. to 178 N on 24 Apr. (Fig. 2B). Mature green avocados were firmer in 2008 than in 2007, and there was a trend toward firmer late-season fruit in 2008. However, there was no correlation between firmness and harvest time when combined over years (Table 3).

Changes in percentage of dry matter and oil content throughout the harvest season. In

Table 3. Correlation coefficients (r) between 'Sharwil' avocado quality attributes and harvest time combined over 2007 and 2008.

Variable	Fruit wt	Initial firmness	Initial color (hue)	Dry matter	Oil content	Days to ripe	Flavor	Texture
Harvest day	–0.40****	–0.01	–0.31***	0.53****	0.52****	–0.38****	0.07	0.03
Fruit weight		0.14**	0.22***	–0.17****	–0.16***	0.18	0.03	–0.03
Initial firmness			0.25***	0.03	–0.01	–0.11	–0.23	–0.54**
Initial color (hue)				–0.18***	–0.18***	0.21	–0.23	–0.41*
Dry matter					0.97****	–0.48**	0.35	0.29
Oil content						–0.48**	0.29	0.27
Days to ripe							–0.29	–0.19
Flavor								0.76****

*, **, ***, ****Significant at $P < 0.05$, 0.01, 0.001, and 0.0001, respectively.

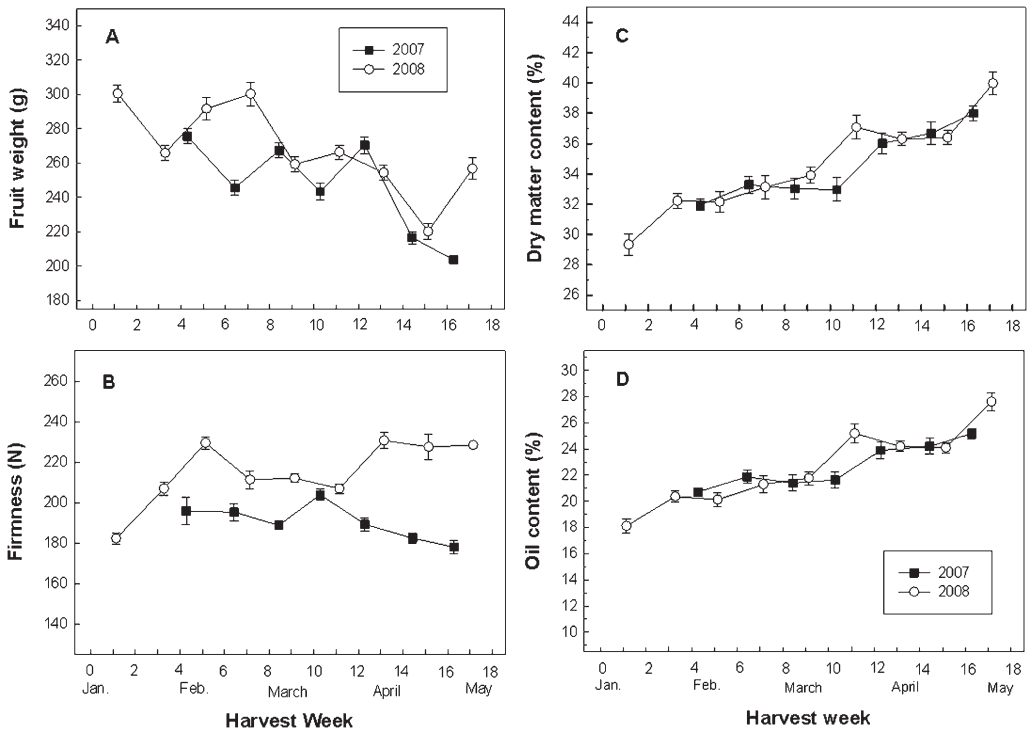

Fig. 2. Fruit weight (**A**), dry matter content (**B**), firmness (**C**), and oil content (**D**) of 'Sharwil' avocados at different times throughout the harvest season.

both years, avocado dry matter and oil contents increased as the harvest season progressed and fruit remained on the tree longer (Fig. 2, C and D), similar to earlier studies with other cultivars (Hofman et al., 2002; Kaiser, 1994; Ozdemir and Topuz, 2004). Dry matter and oil contents showed moderate, significant ($P < 0.0001$) correlations with the time of harvest (Table 3). Mean dry matter content ranged from 32% (30 Jan.) to 38% (24 Apr.) in 2007, and from 29% (8 Jan.) to 40% (29 Apr.) in 2008 (Fig. 2C). Percentage of oil content increased concurrent with dry matter content, and ranged from 21% to 25% in 2007 and from 18% to 28% in 2008 (Fig. 2D). In comparison, the oil content of 'Hass' fruit increased from 11% to 20% over a 3-month harvest period and did not change during ripening (Ozdemir and Topuz, 2004).

The steady increases in dry matter agreed with a previous study for 'Sharwil' avocados (Nujiraapakoran, 1993). Also, 'Hass' avocado dry matter increased during the harvest season from 21.6% to 31.1% in Turkey (Ozdemir and Topuz, 2004), from 25% to 35% in Australia (Whiley et al., 1996), and from 27.7% to 36.8% in New Zealand (Clark et al., 2007). In contrast, Ranney (1991) reported that dry matter did not always increase in late-season avocado harvested in California, and varied from location to location within a short distance.

The dry matter and oil contents of individual 'Sharwil' avocados were highly correlated ($r = 0.97$) (Table 3), and percentage of oil content could be predicted from dry matter content using a linear regression model ($R^2 = 0.93$; $y = -6.18 + 0.83x$) (Fig. 3). The results agree closely with the high correlation ($r = 0.96$) reported for dry matter and oil content of 'Hass' avocados (Lee et al., 1983) and support the basis for using dry matter as a maturity index.

Fruit ripening, flavor, and texture throughout the harvest season. All harvested avocados softened normally, regardless of year, orchard location, or harvest season (data not shown). Ripe fruit had a mean firmness of 5.3 N (±0.3). Late-season fruits softened significantly faster (about 2 d faster) than early season fruits, except for the last harvest in 2007 (Fig. 4A). Overall, the harvest time and the number of days to ripen were negatively correlated ($r = -0.38$, $P < 0.0001$) (Table 3). This supports the previous finding that postharvest ripening accelerates throughout the season (Bower and Cutting, 1988; Eaks, 1980; Kaiser, 1994). A decrease in the number of days to soften was associated with peak ethylene production for late-season 'Hass' avocados (Eaks, 1980).

Although dry matter and oil contents increased as the harvest season progressed, the fruit flavor and texture did not change (Fig. 4, B and C). The texture of ripe fruit was negatively correlated with the initial firmness and skin color at harvest (Table 3), indicating that some hard green fruit had lower texture scores after ripening. A high correlation was found between the texture of the avocado and its taste ($r = 0.76$) (Table 3). The fruit tasted at different harvest dates had acceptable sensory quality, including those with the lowest mean oil contents (18%) (Figs. 2D and 4B). For other cultivars, the minimum mean oil content for acceptable flavor was

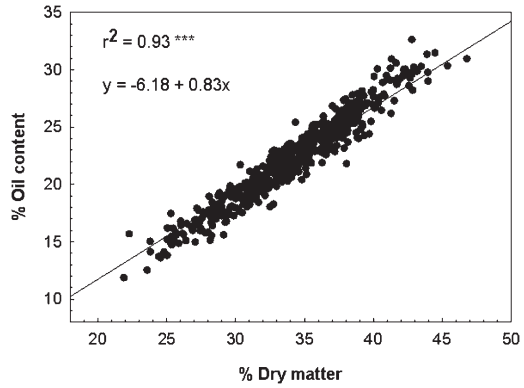

Fig. 3. Relationship between dry matter and oil contents for 'Sharwil' avocados ($n = 554$).

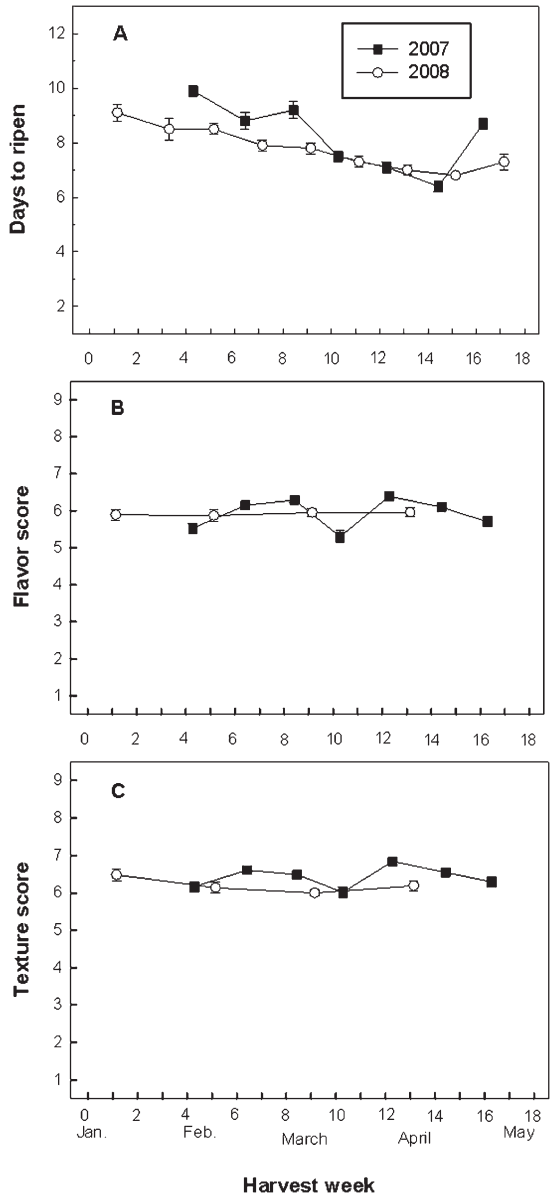

Fig. 4. The number of days to ripen, defined at fruit softening to <10 N (**A**), flavor (**B**), and texture (**C**) for 'Sharwil' avocados at different times throughout the season.

11.2% for 'Hass', 10.3% for 'Zutano', 10% for 'Fuerte', and 8.7% for 'Bacon'; however, these values varied by about 5%, depending on cultivar and location (Lee and Coggins, 1982; Lee et al., 1983). The minimum oil content of 12% required by the Hawaii Department of Agriculture (HDOA) for fancy and number 1 grades of avocado may not be adequate for 'Sharwil' fruit. However, to set a higher maturity index, expanded sensory testing is needed for avocados with 12% to 18% oil contents.

Based on our results, growers marketing fruit with a minimum of 18% oil content can be assured of acceptable quality. At 18% oil, 'Sharwil' fruit had 29% dry matter. Percentage of dry matter has replaced oil content as the key maturity standard in California and worldwide (Lee and Coggins, 1982; Lee et al., 1983; Woolf et al., 2004). In California, the minimum dry matter content for harvest maturity of the major cultivars is: 'Hass' (20.8%), 'Zutano' (18.7%), 'Fuerte' (19.0%), and 'Pinkerton' (21.6%) (Woolf et al., 2004). Mexico requires 21.5% dry matter for legal maturity of 'Hass' (Salazar-Garcia et al., 2005). In New Zealand, the minimum standard is 24% dry matter for exported avocados (Clark et al., 2007). For 'Sharwil' avocados grown in Hawaii, 21.9% dry matter corresponded to the 12% minimum oil content standard of the HDOA. Typically, the legal maturity standards for avocados are designed to prevent marketing of noticeably immature fruit and do not serve as good guidelines for marketing fruit with superior edible quality. Therefore, exporters of high-value 'Sharwil' avocados will benefit from marketing fruit with ≥29% dry matter content.

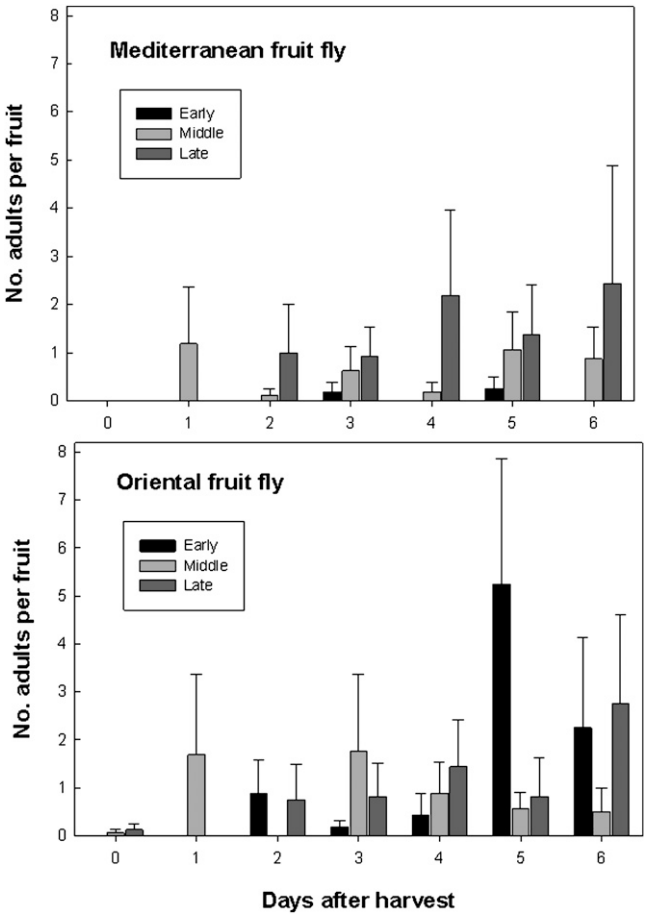

Fig. 5. Infestation levels of 'Sharwil' avocados challenged with Mediterranean fruit fly and oriental fruit fly gravid females at various times after harvest. Fruit were harvested in January (early), April (middle), or May (late) 2008.

Fruit fly infestation. Successful export of 'Sharwil' avocados will depend on the adoption of an approved quarantine treatment or protocol that reduces the risk of fruit fly infestation of the shipped product. Avocado was a poor fruit fly host immediately after harvest, but became an increasingly favorable host as fruit ripened after harvest (Fig. 5). This is consistent with previous infestation studies with 'Sharwil' fruit (Armstrong, 1991; Oi and Mau, 1989). In 2007, no fruit flies emerged (through natural infestation) from a total of 450 field-collected mature-green fruit, nor did any fruit flies emerge from the laboratory cage-forced infestation tests. In 2008, analysis of variance on the number of adult flies emerging from fruit was not significant ($P > 0.1$) for the effect of season (early, middle, or late) or day (0–6 d after harvest) or the season by day interaction for Mediterranean fruit fly or the oriental fruit fly (Fig. 5). Few 'Sharwil' fruit were infested by Mediterranean or oriental fruit fly, but the trend was that the number of adults developing from fruit increased as the number of days after harvest increased. When fruit were exposed to flies on the day of harvest (day 0), none were infested by Mediterranean fruit fly ($n = 48$ fruit) and only two fruit of 48 were infested by oriental fruit fly, producing a total of three adults. Infestation rates increased on subsequent days after harvest. On day 5 after harvest, five fruit of 48 were infested by Mediterranean fruit fly and produced 43 adults, whereas eight of 48 fruit were infested by oriental fruit fly and produced 106 adults. In general, the level of infestation of ripe 'Sharwil' avocado was low compared with a preferred host such as papaya. Ripe papaya controls produced 0.57 Mediterranean fruit fly adults/g and 0.50 oriental fruit fly adults/g compared with 0.0037 adults/g and 0.01 adults/g, respectively, for the 5-d-old avocados. Although fruit are generally poor hosts at harvest, even some hard fruit may become infested, and susceptibility to infestation increased 1 d after harvest for both fruit flies. Therefore, harvested fruit should be covered in the field and packed as soon as possible to reduce the risk of infestation.

Although harvested mature fruit increased in oil content and dry matter as the season progressed, fruit fly infestation levels at harvest were uniformly low throughout the season (Fig. 5). In this study, no fruit were susceptible to infestation with Mediterranean fruit fly at harvest time, and very few fruit were susceptible to infestation by oriental fruit fly. This made it impossible to calculate statistical correlations between fruit fly numbers and dry matter, oil content, or fruit firmness. The fact that relatively few 'Sharwil' fruit were attacked by Mediterranean fruit fly and oriental fruit fly may have obscured seasonal effects on susceptibility to infestation.

There is strong interest in Hawaii in exporting 'Sharwil' avocados to the American mainland. Methyl bromide and cold quarantine treatments to control fruit flies are approved for export of 'Sharwil' avocado, but are not used due to degradation in fruit quality and reduced shelf life (Nishijima et al., 1995). Armstrong (1991) suggested that fruit could be exported safely as a nonhost using a systems approach where fruit are harvested with stems attached and brought to the packinghouse within 12 h, culled to remove damaged fruit, and packed in fruit fly-proof cartons. A systems approach for export of Hawaii 'Sharwil' avocados to the American mainland based on nonhost status was approved by USDA APHIS, but the rule was rescinded in 1992 when live oriental fruit fly larvae were found in mature green fruit attached to the tree. Recently, a proposal was submitted to export 'Sharwil' avocados using a modified systems approach based on poor host status, limited distribution (28 northern states during the winter months of November through March), and low fruit fly prevalence. A similar approach was used to import

Mexican 'Hass' avocados from 1997 to 2001 (Peterson and Orden, 2006). Systems approaches are complex (Jang, 1996) and growers can lose certification if fruit fly densities in orchards exceed predetermined levels. A heat shock pretreatment for inducing cold tolerance in 'Sharwil' avocado fruit before quarantine cold treatment has been developed (Sanxter et al., 1994), thus minimizing CI. Due to the complexities in developing, validating, and operating any systems approach (Follett and Neven, 2006), use of the cold treatment might be the simplest option for Hawaii growers to export 'Sharwil' avocados.

Conclusions

There were minor differences in fruit quality for 'Sharwil' avocados harvested in 2007 and 2008, suggesting that fruit quality can be consistent from one year to the next if the weather remains stable. The 'Sharwil' avocado typically had high oil content, averaging 22.3% of its fresh weight. The fruit accumulated greater dry matter and oil contents as the harvest season progressed, and late season fruit ripened faster than early and midseason fruit. The increase in oil content had no effect on the flavor or texture of avocado, which did not change throughout the season. Percentage of dry matter and oil content were highly correlated (r = 0.97). Fruit with a minimum mean oil content of 18% had 29% dry matter and acceptable sensory quality. Avocado exporters could use 29% dry matter as a maturity index for marketing high-value fruit. Although 'Sharwil' avocados were a poor host to Mediterranean and oriental fruit flies throughout the harvest season, a quarantine treatment or protocol is still required to export avocados. The poor host status of the fruit is one component of a proposed systems approach for quarantine security that also includes low prevalence of fruit flies in the orchard, shipment of mature green fruit, and limited distribution. An alternative for exporting 'Sharwil' fruit is to use a heat-shock pretreatment with the approved quarantine cold treatment.

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