J. Amer. Soc. Hort. Sci. 108(3):390-394. 1983.

Maturity Studies of Avocado Fruit Based on Picking Dates and Dry Weight

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ADDITIONAL INDEX WORDS. *Persea americana,* maturity standard, taste panel

ABSTRACT. **Avocado *(Persea americana* Mill.) fruit from various locations in California were analyzed for oil and subjected to taste tests every 2 weeks throughout the fruiting season over a period of 5 years. Oil content at acceptable taste differed among cultivars, and the 8% requirement was too low to serve as a good maturity standard for many cultivars. While the date of acceptable taste of fruit grown at the same location was not significantly different from year to year, it varied significantly among and within the widespread avocado production areas. Dry weight, which was highly correlated with increasing oil content, was evaluated as a maturity index. The dry-weight analysis with a microwave oven was much easier than determining oil content. The average dry weight at 8% oil (the existing legal standard in California) was 19.4% for 'Bacon', 19.1% for 'Fuerte', 19.8% for 'Hass', 18.9% for 'Pinkerton', and18.4% for 'Zutano' fruit. Dry weight at acceptable taste was 20.0% for 'Bacon', 21.0% for 'Fuerte', 22.8% for 'Hass', 20.0% for 'Pinkerton', and 20.2% for 'Zutano'.**

Physiological maturity in an avocado fruit can be defined as the stage of development where most growth has occurred, while ripeness suggests a readiness for consumption. On the other hand, horticultural or "commercial" maturity can be defined as the developmental stage where harvested fruit will undergo normal ripening and provide good eating quality. The price of fruit is usually high early in the picking season, encouraging the harvest of immature fruit which do not ripen properly, but become watery, rubbery, flavorless, shriveled, and blackened.

Identification of horticultural maturity is difficult for many fruit, especially avocado, because maturation is not accompanied by changes in external appearance. Moreover, mature avocado fruit do not ripen on the tree, but soften several days after being picked. Thus, it is difficult to judge in advance whether a fruit is mature enough to ripen satisfactorily. Since acceptable eating quality depends on flavor, aroma, color, and texture, a taste panel analysis of ripe fruit is the only true test of horticultural maturity. However, taste-panel testing can occur only after ripening. An objective test which is highly correlated with acceptable taste would be desirable (12).

Received for publication May 27, 1982. Special acknowledgments are due toJ. B. Biale for his suggestions and L. A. Willis for her collaboration. This study was supported by the California Avocado Commission. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations this paper therefore, must be hereby marked *advertisement* solely to indicate this fact.

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To maintain consumer confidence and to assist growers in developing markets for their fruit, the California Avocado Standardization Bill was signed on July 24, 1925. Under this law, "It is illegal to sell or offer for sale avocados that are immature or overripe. Avocados shall not be considered mature when the edible portion shows an oil content of less than 8% by weight by chemical analysis" (22). In avocado fruit, oil content is high enough to be measured and its increase is closely related to fruit development. However, maturity based on 8% oil has never been completely satisfactory because oil content at acceptable taste varies among cultivars.

Fig. 1. Map of sampling locations.

Petroleum ether extraction of dried tissue in a Soxhlet extractor is the standard method for analyzing oil content, but this method is too slow to be generally useful to the avocado industry. A shorter refractometric method (16) which involves Halowax oil (monochloronaphthalene) as a solvent is the official method for determining oil in avocado fruit, but the inconsistent refractive index of Halowax oil, temperature-dependent readings, difficulty in reading the small scale, many procedural transfers, and expensive equipment make the procedure unsatisfactory for most growers (15). Also, Halowax oil is a suspected carcinogen and will not be available in the future.

The numerous properties that have been tested as possible maturity standards have been reviewed intensively by Erickson (3), Lee (14), and Lewis (17). In general, changes in these properties during maturation were small, variable, or erratic. This study examined the feasibility of establishing picking dates in California and the practicality of dry-weight analysis as an index of maturity.

Materials and Methods

Starting in September, 5 major avocado cultivars ('Bacon', 'Fuerte', 'Hass', 'Pinkerton', and 'Zutano') were collected every 2 weeks from various locations in California (Fig. 1). To induce uniform ripening, the fruit were treated with 100 ppm ethylene for 36 hr at 20°C and 90% relative humidity. Ethylene-treated fruit were then moved into an incubator with normal atmosphere at 20°. As each avocado ripened, it was moved to 4° until all fruit were ripe, when they were subjected to oil and taste analysis.

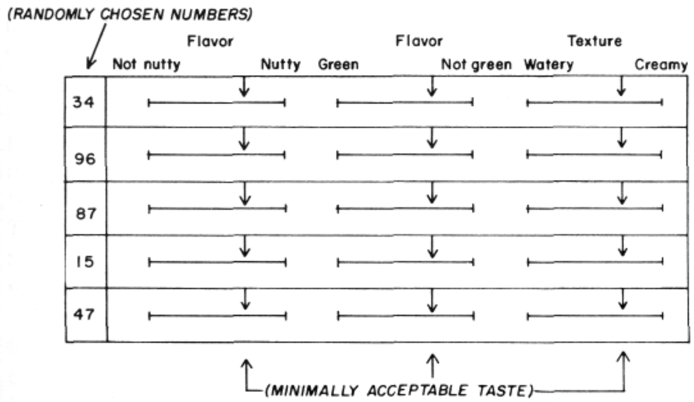

Fig. 2. Taste panel score sheet.

A taste score sheet (Fig. 2) provided 3 lines for each ripe fruit for rating "nuttiness", "greenness" of flavor, and "wateriness" of texture. An arrow marked over each line denoted the beginning of acceptable taste. A piece of each fruit (1 x 1 x 4 cm) was placed on each taste panelist's tray above its assigned code number.

The 20 taste-panel members were selected for their abilities to discern certain minimum quality characteristics such as saltiness, bitterness, sweetness, and acidity, as well as to detect the odd sample in triangle tests of avocado fruit. In analyzing taste-panel data, the panelists' marks on each rating line were measured using a ruled template with divisions numbered 0 to 10. The average value of the 3 rating lines provided a rating for each fruit.

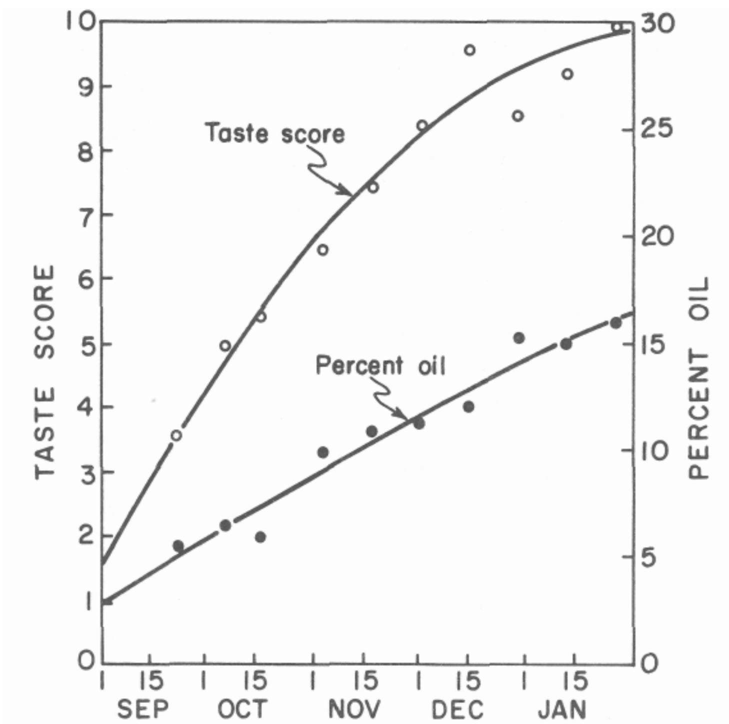

Fig. 3. Taste and oil development during maturation of 'Fuerte' fruit grown at Irvine. Each point represents the mean value of 6 fruit. These data, which are representative of a large number of data sets, were collected in 1976.

For dry-weight and oil analyses, the avocados were quartered longitudinally, peeled, and pitted. A potato peeler was used to take thin slices of tissue from one cut surface of each quarter. About 10 g of tissue were put into a tared Petri dish. These dishes were weighed and set uncovered in a microwave oven (Litton 520; P.O. Box 9461, Minneapolis, MN 55440; 650 watts, 2450 MH). The avocado slices were dried to constant weight (about 15 min at high power), after which dry weight was calculated as a percentage of fresh weight. The dried tissue was macerated with a mortar and pestle and a sub-sample (about 1g) was subjected to standard Soxhlet extraction oil-analysis procedures.

Results and Discussion

Taste scores generally increased rapidly as fruit matured. For example, the taste score of 'Fuerte' fruit grown at Irvine increased quadratically, attaining minimum acceptable taste (taste score 7) on November 7 (Fig. 3). The oil content of 'Fuerte' fruit of minimum acceptable taste was 9.6%. At 8% oil, these fruit had an average taste score of 5.8, considerably below minimum acceptable taste.

Table 1. Percent oil[z] at acceptable taste levels.

Cultivar	Location	No. years	Oil at minimum acceptable taste[y] (%)
Bacon	Corona	1	7.5
	Irvine	1	7.7
	Santa Barbara	1	7.8
	San Marcos	1	9.2
	Santa Paula	2	10.4
	Valley Center	2	9.7
	Avg		8.7
Fuerte	Fallbrook	4	9.3
	Highland Valley	2	8.4
	Irvine	5	10.6
	San Marcos	1	11.7
	Santa Paula	1	11.0
	Valley Center	2	9.9
	Vista (high)	1	10.4
	Vista (low)	1	8.6
	Avg		10.0
Hass	Fallbrook	1	9.1
	Irvine	2	9.9
	Santa Paula	1	14.5
	Avg		11.2
Pinkerton	Corona	1	8.3
	Fallbrook	1	9.5
	Santa Paula	1	9.2
	Avg		9.0
Zutano	Corona	3	9.8
	Fallbrook	5	10.7
	Highland Valley	2	8.2
	Irvine	3	11.4
	Lindcove	2	9.0
	Porterville	2	10.5
	Santa Paula	1	12.0
	Valley Center	2	10.5
	Avg		10.3

[z]Based on freshly picked rather than ripened fruit.
[y]Taste level 7.

The percent oil in fruit of minimum acceptable taste varied by as much as 5%, depending on cultivar and location (Table 1). When the means were calculated for each cultivar at different locations, the percent oil at acceptable taste was 8.7% for 'Bacon', 10.0% for 'Fuerte', 11.2% for 'Hass', 9.0% for 'Pinkerton', and 10.3% for 'Zutano' fruit. The mean value for all 5 cultivars was 9.8%. It is clear that 8% oil is too low to be a good maturity index.

Hodgkin (10) also found that 8 % oil was too low for acceptable taste for many cultivars in California. According to Hope (11), 'Fuerte' fruit in Australia did not develop acceptable taste until the oil content attained 15%. In California, the adoption of 8% oil as the legal maturity standard was made without a formal taste-panel analysis and was the result of compromise. Assigning minimum oil levels to each cultivar was believed to be too complicated. Because 8% oil was not considered too high for any cultivar, it was adopted to protect consumers from grossly immature fruit.

In tests of 2 cultivars over 5 consecutive seasons, the mean date of acceptable taste was November 4 for 'Fuerte' at Irvine and November 18 for 'Zutano' at

Fallbrook (Table 2). During this period, the dates of acceptable taste varied only 13 days for 'Fuerte' and 9 days for 'Zutano', suggesting that a range of picking dates may be assigned.

Table 2. Dates of acceptable taste development for 'Fuerte' and 'Zutano' fruit throughout the 5-year period.

		Dates of acceptable taste					
Cultivar	Location	1976	1977	1978	1979	1980	Mean
Fuerte	Irvine	Nov 7	Oct 30	Oct 30	Nov 1	Nov 12	Nov 4
Zutano	Fallbrook	Nov 13	Nov 18	Nov 17	Nov 22	Nov 20	Nov 18

The dates of acceptable taste for 'Bacon' and 'Zutano' fruit at various locations are summarized in Table 3. The locations shown in Fig. 1 were grouped into 3 major avocado growing regions: the San Diego/Orange County area, the Ventura Coastal area, and the Tulare Inland area. There was no significant difference in the date of acceptable taste of 'Bacon' fruit among 4 locations in the San Diego/Orange County area, or between 2 locations in the Ventura Coastal area. The mean date of acceptable taste within the San Diego/Orange County areas was November 13. However, the corresponding date within the Ventura Coastal area was December 7, 24 days after acceptable taste developed in the San Diego/Orange County area. Apparently the cool temperature and high humidity typical of the coast delayed maturity.

Table 3. Variability of dates of acceptable taste in various locations.

Cultivar	Area	Location	No. years	Dates of acceptable taste
Bacon	San Diego/ Orange County	Corona	1	Nov 7
		Irvine	1	Nov 3
		San Marcos	1	Nov 16
		Valley Center	2	Nov 16
	Ventura Coastal Area	Santa Barbara	1	Dec 14
		Santa Paula	2	Nov 29
Zutano	Tulare Inland Area	Lindcove	2	Oct 19
		Porterville	2	Oct 25
	San Diego/ Orange County	Corona	3	Dec 2
		Fallbrook	5	Nov 18
		Highland Valley	2	Nov 22
		Irvine	3	Nov 10
		Valley Center	2	Nov 27
	Ventura Coastal Area	Santa Paula	1	Dec 9

'Zutano' fruit at 2 locations in the Tulare Inland area matured on October 22 on the average, with no significant difference between locations. 'Zutano' fruit in the San Diego/Orange County area matured on November 22. Fruit from Corona matured later than fruit from the other locations in the San Diego/Orange County area, perhaps due to cool night temperatures in the valley in which the grove is located. Fruit from Santa Paula in the Ventura Coastal area had acceptable taste on December 9. Fruit in the Tulare Inland area may have matured earlier than fruit in the southern area because of higher average temperatures during the growing season in the Tulare Inland area.

Maturity based on assigned picking dates appears to be satisfactory in Florida (6, 7, 8, 9, 20, 21), where the avocado growing region is small (essentially Dade County) and climatically more uniform than in California. In California, it may be possible to divide the avocado growing area of the state into at least 3 different regions (the San Diego/Orange County area, the Ventura Coastal area, and the Tulare Inland area) with different picking dates for a given cultivar. However, such a process would encourage harvesting in one area for illegal marketing in another. Also, differences in maturity for a cultivar within an area based on microclimatic variations are a problem.

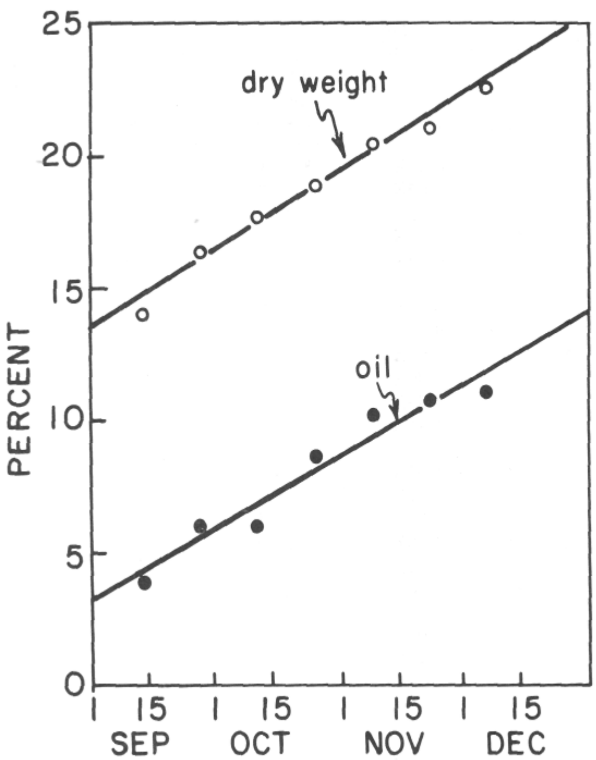

Fig. 4. Percent oil and percent dry weight during development and maturation of 'Hass' fruit at Escondido. Each point represents the mean value of 6 fruit. These data, which are representative of a large number of data sets, were collected in 1981.

Haas (5) noticed that the percent dry weight of the avocado fruit increased with maturity. Recently, Morris and O'Brien (18) in New South Wales, Australia, found a close relationship between oil content and dry weight and suggested a minimum maturity standard of 21% dry weight. In California, preliminary research by the authors indicated a close correlation between oil content and dry weight during maturation. The incremental dry weight increase during development was due mainly to oil (Fig. 4).

When percent dry weight was plotted against percent oil during development, the close relationship became clear (Fig. 5). Linear regression analysis of all the data points for 'Hass' fruit at Escondido produced the equation, Y = 10.67 + 1.0IX, in which percent dry weight (Y) is expressed as a function of percent oil (X). A high correlation coefficient (r = 0.96) indicated the close relationship between dry weight and oil content. The coefficient of determination ($r^2 = 0.93$) implied that 93%of the variation of percent dry weight could be attributed to variation of percent oil and 7% to random factors.

Correlation coefficients and equations for the major cultivars at several locations are summarized in Table 4. In all cases, the correlation coefficients were highly significant (1% level). Regression coefficients of the equations varied from 0.7 to 1.1 and were close to unity in many cases. The percent dry weight equivalent to 8% oil can be obtained from these equations or by extending a line from 8% oil to the regression line and then to the Y-axis. For 'Hass' fruit at Escondido, 18.8% dry weight was equivalent to 8% oil. The percent dry weights of other cultivars at different locations when 8% oil developed are also included in Table 4. The variation was rather small, even in fruit from widely different locations. Average dry weight at 8% oil was 19.4% for 'Bacon', 19.1% for 'Fuerte', 19.8% for 'Hass', 18.9% for 'Pinkerton', and 18.4% for 'Zutano' fruit. The overall average value for these 5 cultivars was 19.1%. At the 5% confidence level, the values for confidence intervals varied within the range of 0.2% to 1.4% as shown in Table 4.

The close relationship between the increase in dry weight and the increase in oil was due to non-oil dry matter remaining fairly constant during the developmental stages that we investigated. Since avocado fruit are composed of water, oil, and non-oil dry matter, the latter can be calculated by subtracting the amount of oil from the percent dry weight. The average values of non-oil dry matter at 8% oil were 11.4 for 'Bacon', 11.1 for 'Fuerte', 11.8 for 'Hass', 10.9 for 'Pinkerton', and 10.4 for 'Zutano' fruit. The mean value for these 5 cultivars was 11.1%. A small variation in these values occurred due to different cultivar and locations. 'Zutano' fruit tended to have less non-oil dry matter than the other cultivars.

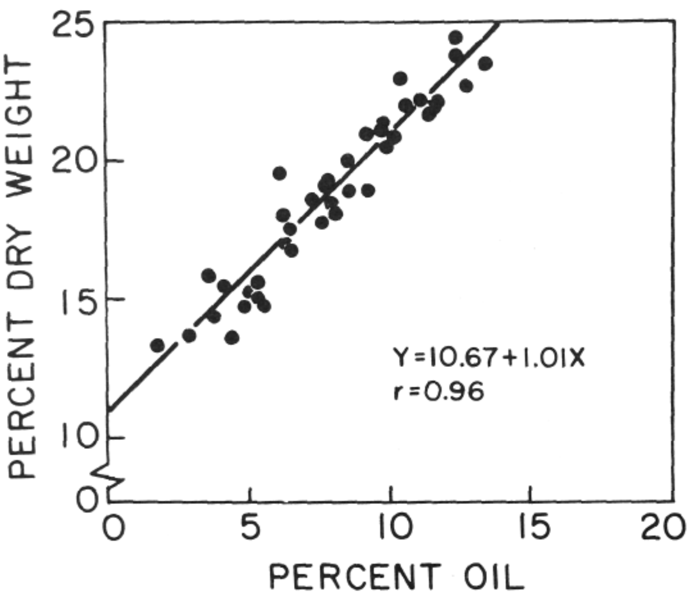

Fig. 5. Relationship between percent dry weight and percent oil during development and maturation of 'Hass' fruit at Escondido. Each point represents one fruit. These data, which are representative of a large number of data sets, were collected in 1981.

Taste-panel analyses demonstrated that 8% oil was too low to serve as a good measure of acceptable taste. Based on taste panel results, acceptable taste occurred when the average percent oil was 8.7% for 'Bacon', 10.0% for 'Fuerte', 11.2% for 'Hass', 9.0% for 'Pinkerton', and 10.3% for 'Zutano'. Equivalent percent dry weights were 20% for 'Bacon', 21% for 'Fuerte', 22.8% for 'Hass', 20% for 'Pinkerton', and 20.2% for 'Zutano' fruit. The mean for these 5 cultivars was 20.8%, which is very close to the Australian maturity standard of 21%.

Analysis of percent dry-weight with a microwave oven is simpler and quicker than the conventional oil analysis as a procedure for determining avocado maturity. Microwave ovens have been used for determining maturity of corn (1, 2, 4) and in quality control of many other food products (13, 19). This method is the most rapid and efficient means for drying samples because water is heated selectively and uniformly throughout the sample. The procedural variability of this method was tested for 5 different cultivars picked on the same date. Twelve samples were taken from a single fruit of each cultivar and dried in a microwave oven. For fruit of about 22% oil, the standard errors among the 5 cultivars ranged from a low of 0.07 to a high of 0.15. The F test in a 2-way analysis of variance showed no significant differences among 12 repetitions. The coefficient of variations was about 1.8%. Thus, little variability in our data was due to laboratory errors. From this standpoint, the dry-weight method is an ideal maturity standard.

The procedure for determining percent dry weight is faster and more accurate than the Halowax method. Because there is a close relationship between percent dry weight and percent oil, percent dry weight could be used as an index of percent oil and as a maturity standard.

Table 4. Correlations between percent dry weight and percent oil during maturation.[z]

Cultivar	Location	Correlation coefficient[y] (r)	Equation	Percent dry wt at 8% oil	$t_{05}S\hat{y}$[x]
Bacon	Corona	0.98	Y = 12.52 + 0.83X	19.1	0.3
	Escondido	0.97	Y = 10.49 + 1.04X	18.8	0.4
	Irvine	0.97	Y = 13.99 + 0.75X	20.0	0.4
	Santa Barbara	0.98	Y = 11.75 + 0.93X	19.2	0.3
	Santa Paula	0.97	Y = 12.97 + 0.84X	19.7	0.3
Fuerte	Corona	0.95	Y = 12.02 + 0.93X	19.5	0.8
	Escondido	0.89	Y = 11.22 + 0.89X	18.4	1.4
	Fallbrook	0.97	Y = 11.35 + 0.91X	18.7	0.5
	Irvine	0.96	Y = 12.45 + 0.90X	19.6	0.7
	Vista (high)[w]	0.97	Y = 11.56 + 0.93X	19.0	0.4
	Vista (low)[w]	0.98	Y = 10.30 + 1.11X	19.2	0.3
Hass	Corona	0.98	Y = 11.87 + 1.01X	20.0	0.2
	Escondido	0.96	Y = 10.67 + 1.01X	18.8	0.4
	Fallbrook	0.97	Y = 11.01 + 1.03X	19.3	0.5
	Irvine	0.95	Y = 11.56 + 1.00X	19.6	0.6
	Santa Barbara	0.96	Y = 13.21 + 0.92X	20.6	0.6
	Santa Paula	0.96	Y = 13.49 + 0.86X	20.4	0.7
Pinkerton	Corona	0.95	Y = 11.11 + 0.95X	18.7	0.6
	Fallbrook	0.98	Y = 9.51 + 1.12X	18.5	0.2
	Santa Paula	0.98	Y = 11.47 + 1.01X	19.6	0.2
Zutano	Corona	0.94	Y = 11.25 + 0.91X	18.6	0.8
	Escondido	0.97	Y = 10.43 + 0.82X	17.0	0.4
	Fallbrook	0.90	Y = 11.32 + 0.81X	17.8	1.2
	Irvine	0.97	Y = 12.02 + 0.88X	19.0	0.6
	Lindcove	0.96	Y = 12.59 + 0.72X	18.3	0.5
	Porterville	0.98	Y = 11.76 + 0.82X	18.4	0.3
	Santa Paula	0.98	Y = 13.91 + 0.68X	19.4	0.5

[z]These data were collected in 1981.
[y]All correlation coefficients were statistically significant at 1% level.
[x]Values for confidence interval calculation.
[w]Refers to high and low elevation sampling sites.

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