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# AVOCADO FRUIT MATURITY

**Charles R. Barmore[1]**

One of the most important criteria for the development of a successful avocado fresh fruit industry is the assurance of quality to the consumer. Quality is the result of several factors: production of disease-free fruit, proper maturity at harvest and correct harvesting and handling procedures. No single factor can be considered the most important; however, it can be said that from a postharvest standpoint, quality begins at harvest with physiological maturity. It is well known that maturity affects both storage and eating qualities (26). Krome (16), a leader in the Florida avocado industry, expressed the importance of maturity in a review article in 1954. He stated "...that since it was large enough to be called an industry, the avocado industry in Florida has been plagued with certain man-made troubles that seem unnecessary but which in fact proved difficult to remedy. These problems have had to do mainly with buyer resistance created by sale of immature fruit..." This problem was not corrected until a satisfactory method for determining maturity was developed and implemented through a Federal Marketing Agreement (24).

Numerous studies on the subject of avocado maturity have been made over the past 50 years. This has led to the development of 2 essentially different commercial methods for determining avocado fruit maturity (discussed below). Because of the importance of maturity to the industry, interest in improving these methods still exists today. A comprehensive review of the literature on the avocado fruit was recently published by Biale and Young (5).

What constitutes a mature fruit and how does one measure maturity? A mature avocado is one that has reached a particular stage in development such that when harvested, it will ripen to an edible condition with acceptable flavor and texture identifiable with that particular cultivar. Conversely, an immature fruit is one that has not yet attained this proper stage of development and, although it will soften, will not attain acceptable eating quality. In addition, an immature avocado held under ripening conditions will often shrivel and become rubbery and discolored (10). The processes associated with the attainment of full fruit size and development of the quality attributes of a mature fruit are known as maturation.

Palatability, even though it is the ultimate test of fruit maturity, does not always provide a practical means of determining maturity, especially on a commercial scale. This is particularly true for those fruits, such as avocados, that are inedible at time of harvest. Any measure of palatability becomes purely "hindsight". However, measurement of palatability is important in the study of maturity. To circumvent this problem, numerous studies have been made investigating the anatomical, biochemical and physiological changes associated with maturation. The anatomical development of the avocado fruit

[1]Assistant Horticulturist, University of Florida. Institute of Food and Agricultural Sciences, Agricultural Research and Education Center, Lake Alfred, FL.

has been investigated rather thoroughly by Schroeder (7, 20) and Valmayor (25). The growth of the avocado fruit follows the single sigmoid curve (Fig. 1). In early-maturing cultivars, the latter portion of the growth curve is generally steep and fruit are still increasing in size at harvest. In the later-maturing cultivars, the growth curve is moderately steep and increases in size have slowed down long before commercial maturity is attained. The early stage of fruit growth, regardless of whether it is an early- or late-maturing cultivar, is characterized by very rapid cell division. Differences in fruit size of cultivars maturing at approximately the same time result primarily from differences in the rate of cell division during the first 6 weeks of development (25).The avocado fruit is unusual in that cell division of the mesocarp parenchyma (flesh) is not restricted to the initial period of growth but also goes on during cell enlargement and even in mature fruit still firmly attached to the tree. In some cases, cell enlargement stops when fruit reaches 50% of its size at full maturity, while cell division accounts for continued growth (7).

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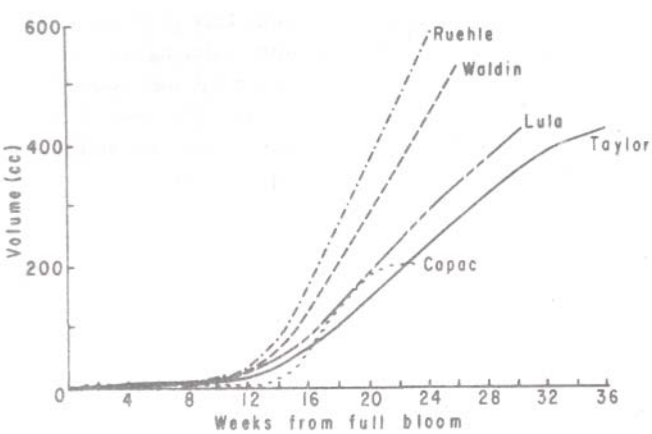


Fig. 1. Average increase in volume of fruit recorded at bi-weekly intervals from full bloom to fruit maturity [Source: Valmayor (25)].

In conjunction with the development of the parenchyma cells of the mesocarp, there is the development of cells specialized for the accumulation of lipids (oils). These cells are known as idioblasts and are believed to differentiate from parenchyma cells (25).

Anatomical studies have been instrumental in explaining the variation in size between cultivars and the differences in growth rate between early- and late-maturing cultivars. However, considerable variation in size can exist among fruit on a tree at any one time. Much of this variation can be attributed to the flowering characteristic of the avocado tree. Individual avocado trees of any 1 cultivar may bloom over a period of several weeks (13, 18). Hatton and Reeder (13) have shown that on a particular tree, avocado fruits originating from known bloom dates are progressively smaller in size from the earliest to the latest bloom date. Additional variation in fruit size can exist among groves of the same cultivar. This is often attributed to differences in production practices, yield, water relations and climatic conditions.

The relationship between size and development or maturity can be used as a determinant of maturity if the above factors which affect size are understood. Researchers studying maturity of Florida avocados in the past have placed major emphasis on this relationship. Studies by Soule and Harding (22) and Hatton and Reeder (10) have shown that, in general, larger fruit have higher flavor ratings than small fruit when tested early in the season at time of minimum acceptability. However, as the season progressed, differences in flavor ratings between large and small fruit became less pronounced. The statistical correlation between size and palatability was substantially improved when days from full bloom to harvest (harvest date) were used as a co-variable in the determination. Soule and Harding (22) also found this correlation to be higher than the correlation between harvest date and palatability.

Additional information on avocado maturity has been obtained from both biochemical and physiological studies. Numerous chemical evaluations have been made in an attempt to identify 1 or more components which would change significantly during maturation and would be consistent among all cultivars. This has not been possible. However, the 1 component which most nearly meets this objective is oil content.

The avocado fruit possesses a remarkable ability to synthesize oils and accumulate levels as high as 30% of fruit weight. It has long been recognized that as the avocado fruit matures, there is a concomitant increase in oil content. This relationship is best exemplified in cultivars which have a high oil content at maximum maturity (Fig 2). Unfortunately, not all avocado cultivars have comparable oil content, nor are they all reasonably high in oil at maturity (15-30%). Oil content for the various cultivars of commercial importance range from a low of 3% to a high of 30% or greater. The cultivars grown in Florida often are low in oil content; whereas, California cultivars are characteristically high in oil content. The differences in oil content between the 2 locations are primarily the results of different racial origin of cultivars which are grown.

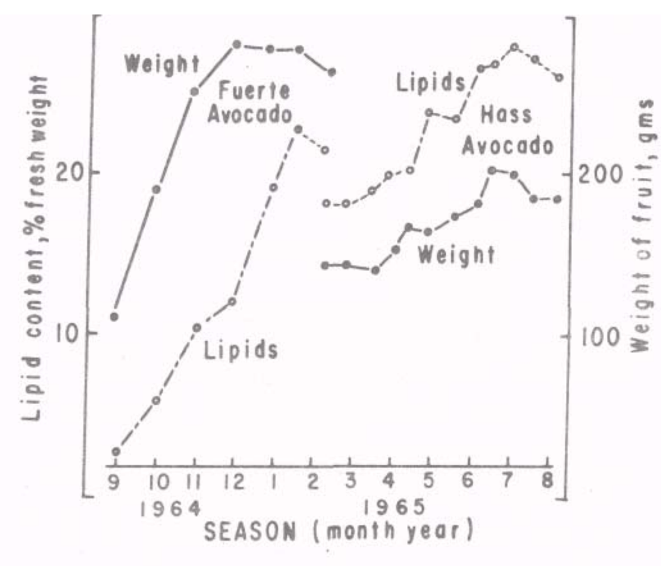


Fig. 2. Seasonal changes in lipids and weight of 'Fuerte' and 'Hass' avocado fruits. [Source: Kikuta and Erickson (15)].

Popenoe (19) classified avocados into 3 races: West Indian, Guatemalan, Mexican.

This classification has become less distinct because of the increasing number of hybrid cultivars. Hatton *et al.* (10) have indicated that nearly 90% of Florida avocados are from hybrid cultivars of unknown parentage. Fruit of the Mexican type have the highest oil content followed by the Guatemalan and West Indian types. The oil content of Florida avocados is low because West Indian and West Indian x Guatemalan hybrids predominate. Conversely, the oil content of California avocados is relatively high due to the prominence of Guatemalan *(e.g.,* 'Hass') and Guatemalan x Mexican hybrids *(e.g.,* 'Fuerte') (10, 12). Seasonal changes in oil content of several Florida and California cultivars and oil content of the different races of avocados produced in Florida are shown in Fig. 2 and 3 and Table 1, respectively.

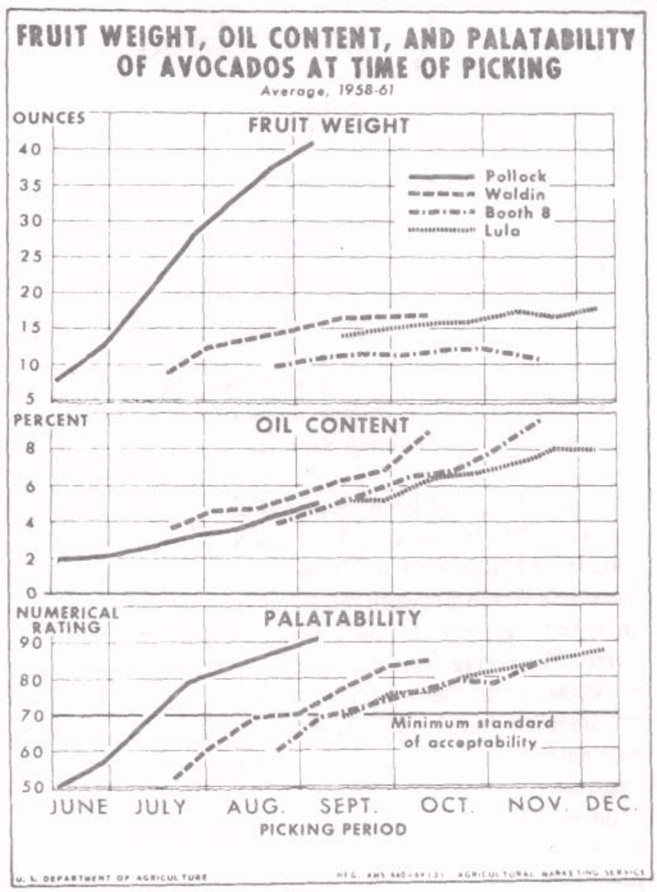


Fig. 3. Seasonal changes in fruit weight, oil content and palatability of 4 Florida avocado cultivars. Ounces x 28.35 = grams. [Source: Hatton *et al.* (10)].

Studies by Kikuta and Erickson (15) have shown that in the 'Fuerte' and 'Hass' cultivars, maximum oil accumulation did not occur until growth had almost ceased. The predominant fatty acid synthesized by the fruit is oleic and is deposited as a triglyceride in the idioblast cells. Concomitant with increase in oil content, there is a significant decrease in water content in the mesocarp (17, 21). Interestingly, the sum of the percentages of water and oil remain fairly constant during this time. However, this relationship has only been studied with fruit having a high oil content.

**Table 1. Oil content when harvested at minimum acceptability of several Florida cultivars according to race.** [z]

| Race/cultivar | Date | Oil content (%) Average | Range |
|---|---|---|---|
| *West Indian* | | | |
| Fuchs | Jun 15 | 3.2 | 2.5 to 3.5 |
| Pollock | Jul l3 | 2.9 | 2.1 to 4.7 |
| Nadir | Jul 27 | 4.5 | 2.5 to 6.2 |
| *Guatemalan* | | | |
| Taylor | Nov 3 | 8.0 | 6.4 to 9.2 |
| Nabal | Nov 24 | 8.3 | 7.2 to 9.9 |
| Wagner | Dec 14 | 14.7 | 14.3 to 14.9 |
| *West Indian* x *Guatemalan* | | | |
| Tonnage | Aug 31 | 4.9 | 4.2 to 5.6 |
| Booth 8 | Sep 8 | 5.6 | 3.7 to 8.6 |
| Lula | Sep 28 | 6.5 | 3.5 to 9.9 |
| Hall | Oct 26 | 8.5 | 7.1 to 9.3 |
| Choquette | Oct 22 | 4.1 | 3.8 to 4.6 |

[z] Date coincides closely with the earliest picking date allowed by the maturity standard for the 1959-60 crop year.

Source: Hatton *et al.* (10).

The avocado fruit is classified as a climacteric fruit with reference to its respiration pattern during ripening (3, 4). Unlike many other climacteric fruits, it will not ripen while attached to the tree (20). Removal from the tree is required to initiate the ripening process. Most of the physiological studies on avocado maturity have basically dealt with the time course of the climacteric pattern of respiration, ethylene production and softening. These events are generally considered to be directly related to the ripening process in mature fruit (Fig. 4). However, it has been reported that for the avocado fruit, respiration pattern and rates and ethylene production were basically similar at various stages of development, but that the time course of these effects did change with maturity. Softening is discernible approximately 2 days after the climacteric peak. The elapsed time between harvest and the climacteric peak, ethylene peak and softening becomes progressively shorter as the fruit matures (27). Adato and Gazit (1) have also shown that the ability of ethylene to trigger the ripening process during the first day after harvest becomes increasingly more effective with advances in maturity. Days required for fruits to soften may be used as a general guide to avocado maturity.

Studies by Zauberman and Schiffman-Nadel (28) and by Barmore *et al.* (2) have shown that the activity of the enzyme pectinmethylesterase (PME) decreases significantly with maturity of the avocado fruit (Fig. 5, Table 2 and 3). The decrease in PME activity was greatest in young developing fruit, while in nearly mature fruit, the decrease was moderate to slight. Data from both studies indicated that although each cultivar did have different levels of PME activity throughout its development, the PME activity at maturity was approximately the same each year for each individual cultivar.

The initial studies on PME activity during maturation indicated that this parameter might be a very good index of maturity. However, as maturity is reached, the rate of decrease becomes very small, often attaining a plateau, making it difficult to select a PME value which would indicate a mature fruit. This was particularly a problem for cultivars which had relatively low PME activity throughout the period measured (2). The use of PME activity is limited to a general approximation of maturity.

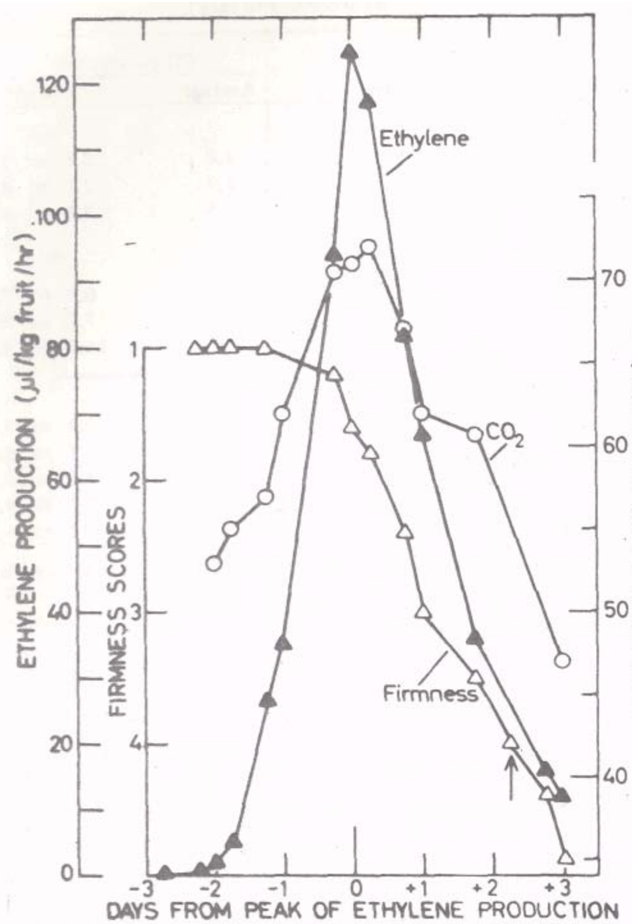


Fig. 4. Relationship between ethylene production, respiration and fruit firmness during ripening. Arrow points to the day on which the fruits were judged edible. [Source: Adato and Gazit (1)].

Several other parameters, both chemical and physical, have been followed during the maturation period. Total soluble solids have been measured during the maturation of several cultivars. No consistent decrease or increase was apparent as maturation progressed. Also, little or no difference was found between large and small fruit (11). Changes in specific gravity during maturation have also been measured. The average specific gravity of the whole fruit tended to decrease as the season progressed; however, there was considerable variation among individual fruit and at any one date

(9). Changes in other chemical constituents during maturation have been reported by others (8, 17, 21). Blumenfield and Gazit (6) have reported that the shriveling of the seed coat is related to fruit maturity. The shriveling of the seed coat of the 'Fuerte' avocado was found to precede the decrease in fruit growth rate. Darkening of the seed coat is also observed at this time and is used in Florida as a criterion of maturity of fruit from seedling trees. However, further use of this character is limited because of its variability (9). Observations on fruit abscission have been made for estimating the maturity period especially for seedlings (10). Change in peel color can be used as an indication of maturity for some cultivars.

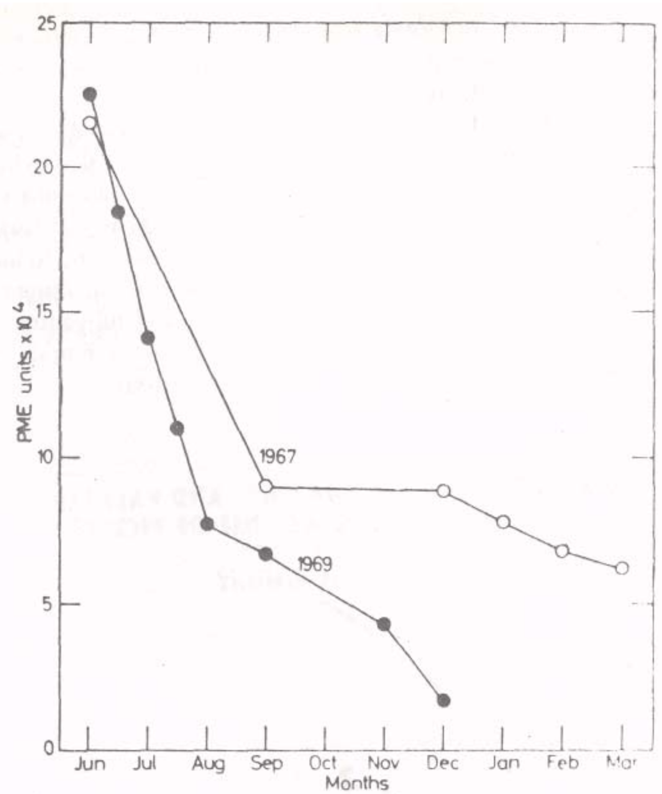


Fig. 5. The activity of pectinmethylesterase (PME) at picking time in 'Fuerte' fruits at various stages of development. [Source: Zauberman and Schiffmann-Nadel (28)].

As one can see, much work has been done studying the maturation process of the avocado fruit. Many of the characters which show a trend with maturation are not applicable for determining maturity on a commercial basis. Their value as a precise criteria is often questionable because of the variation among fruit at any 1 sampling date and gradual change from 1 date to another. Fortunately, from these studies, 2 sets of standards have been developed and are being used commercially in the United States to determine avocado maturity. These are based on oil content, used by the California industry, and minimum fruit weight or diameter and earliest harvest date (days from full bloom), used by the Florida industry. The former set of standards have been in use since the 1930's, whereas Florida did not institute maturity standards until the late 1950's.

**Table 2. Pectinmethylesterase (PME) activity and palatability evaluations of 3 Florida cultivars tested during the 1974 season.**

| Cultivar | Harvest date | PME activity ($x10^4$) | Palatability | |
|---|---|---|---|---|
| | | | Pass | Fail |
| Booth 8 | 24Aug | 90 | 0 | 10 |
| | 30 Aug | 74 | 3 | *6* |
| | 6 Sep | 71 | — | — |
| | 13 Sep | 49 | 9 | *3* |
| | 20 Sep | 52 | 17 | *5* |
| | 27 Sep | 55 | 14 | *8* |
| | 4 Oct | 51 | 11 | *2* |
| | 11 Oct | 32 | — | — |
| | 18 Oct | 33 | 25 | 1 |
| Waldin | 27 Jul | 120 | — | — |
| | 3 Aug | 133 | — | — |
| | 10 Aug | 120 | — | — |
| | 17 Aug | 81 | 1 | 17 |
| | 24 Aug | 72 | 3 | 6 |
| | 30 Aug | 65 | 4 | 4 |
| | 6 Sep | 56 | 11 | 0 |
| | 13 Sep | 47 | 10 | 2 |
| | 20 Sep | 43 | 14 | 0 |
| Lula | 27 Sep | 27 | 1 | 18 |
| | 4 Oct | 27 | 9 | *2* |
| | 11 Oct | 23 | 7 | *2* |
| | 18 Oct | 21 | 25 | *2* |
| | 25 Oct | 22 | 25 | *0* |
| | 1 Nov | 27 | 26 | *0* |
| | 8 Nov | 21 | 26 | *0* |
| | 15 Nov | 20 | 24 | 0 |
| | 22 Nov | 20 | 27 | 0 |

The California avocado industry has always maintained that oil content constitutes one of the main criteria in determining maturity. For their relatively high-oil-content cultivars, this is no doubt, correct. The State of California has set a minimum of 8% oil based on fresh weight of the fruit, exclusive of the skin and seed, as their standard of maturity for all cultivars. Once the 8% oil content has been reached in the test sample, those fruit to be picked are selected on the basis of external characteristics and size noted on those fruit used for the test sample. The maturity dates for the various cultivars vary with the production or climatic zone (14).

The use of oil content for determining maturity of Florida avocados has not been found to be practical (11, 18). Studies by Hatton *et al.* (14) have shown that even though oil content does increase with maturity, there is considerable variation in oil content among and within individual cultivars. A part of this problem may be attributed to the previously mentioned low oil content of most Florida cultivars. A considerable number of these cultivars never reach 8% at maximum maturity; whereas, over 20% is not uncommon in most of the California cultivars. The change in oil content during maturation is gradual in these low-oil-content cultivars and a 1 or 2% variation among samples would be critical (Fig. 3). The fact that Florida avocados are relatively low in oil content does not mean that the quality of these fruit is also low. High oil content is no assurance of good flavor (10, 23).

**Table 3. Pectinmethylesterase (PME) activity and ripening data of 3 Florida avocado cultivars tested during the 1975 season.**

| Cultivar | Harvest date | PME activity ($x 10^4$) | Palatability | | Shrivel[z] SER |
|---|---|---|---|---|---|
| | | | Pass | Fail | |
| Booth 8 | 30 Aug | 51 | 2 | 7 | X |
| | 6 Sep | 33 | 7 | 2 | X |
| | 13 Sep | 32 | 7 | 2 | X |
| | 20 Sep | 32 | 6 | 2 | |
| | 27 Sep | 28 | 9 | 0 | |
| Waldin | 26 Jul | 50 | 7 | 1 | X |
| | 2 Aug | 45 | 7 | 1 | |
| | 9 Aug | 50 | 7 | 3 | X |
| | 16 Aug | 45 | 9 | 0 | X |
| | 23 Aug | 42 | 9 | 0 | |
| Lula | 27 Sep | 16 | 5 | 4 | |
| | 4 Oct | 19 | 5 | 4 | |
| | 11 Oct | 20 | 0 | 9 | X |
| | 18 Oct | 20 | 9 | 0 | |
| | 25 Oct | 20 | 9 | 0 | |

[z] Indicates 2 or more of 9 fruit showed shriveling and/or stem-end rot following ripening.

A Federal Marketing Agreement specifies separate maturity standards for each cultivar in Florida. These standards are based on minimum fruit weight or diameter and earliest permitted harvest date (days from full bloom to harvest). These standards were developed basically from data collected over several years on the average size of mature fruit and number of days from full bloom for the cultivar to reach maturity. To aid further in the determination of maturity, a sample of fruit meeting the size requirements is ripened under specified conditions and judged for flavor, moisture loss and external shriveling. The present procedure requires that sampling of fruit for maturity testing begin prior to the earliest harvest date. If the test sample representing the earliest harvest date does not receive a satisfactory score, the earliest harvest date is changed to a later date. Conversely, changes in minimum size requirement and/or earliest harvest date can be made if fruit not meeting these requirements are nevertheless passing the maturity test as based on flavor and ripening characteristics and the requested change is then approved by the United States Department of Agriculture (24). The maturity standards for each season are set each year several months prior to the marketing season. This procedure allows consideration to be given to variation in growing conditions throughout the season. An example of these maturity standards for several Florida cultivars is shown in Table 4.

**Table 4. Florida maturity standards and shipping schedule for several major avocado cultivars (1973-74).**

| Variety | Date A[z] | Min. wt[y] (g) | Min. diam. (cm) | Date B | Min. wt[y] (g) | Min. diam[y] (cm) | Date C | Min. wt[y] (g) | Min. diam.[y] (cm) | Date D[x] |
|---|---|---|---|---|---|---|---|---|---|---|
| Fuchs | 6/25 | 397 | 8.10 | 7/9 | 340 | 7.62 | 7/23 | 284 | 7.30 | 8/13 |
| Pollock | 7/9 | 510 | 9.37 | 7/16 | 454 | 8.73 | - | - | - | 7/30 |
| Waldin | 8/20 | 454 | 9.05 | 9/3 | 397 | 8.75 | 9/17 | 340 | 8.60 | 10/1 |
| Tonnage | 9/3 | 397 | 8.26 | 9/10 | 340 | 7.62 | 9/17 | 284 | 7.14 | 9/24 |
| Lula | 10/22 | 510 | 9.37 | 11/5 | 397 | 8.57 | - | - | - | 11/19 |
| Taylor | 10/29 | 397 | 8.41 | 11/12 | 340 | 7.94 | - | - | - | 11/26 |

[z] No fruit may be shipped before this date.
[y] Where a minimum weight and a minimum diameter are given, fruit which meets either standard may be shipped.
[x] No restrictions on size or weight on or after this date.

Development of the preceding maturity standards has not been easy nor without controversy. They are not without weaknesses, but they have proved to be a reliable maturity index over the years. A single test such as used by California is ideal, but not always possible in other locations. The procedure used by the Florida industry appears time-consuming and it is. Approximately 54 cultivars were evaluated, each several times, last season with this method. The procedure for oil determination is also tedious, but California has only about 5 cultivars, 2 of which, 'Fuerte' and 'Hass', comprise over 90% of the production.

What does the future hold for new or improved ways of determining maturity? It would be safe to assume that no immediate changes in either method will be made within the next few years, at least not in the United States. There is now research on flavor components of avocados underway by the USDA Citrus and Subtropical Products Laboratory at Winter Haven, Florida. This will produce some very interesting results, some of which might be applicable to maturity standards—an area that has not been thoroughly investigated in the past. Precursors of the characteristic flavors in mature avocados might be important factors to consider for future maturity studies. An important point to consider in researching new methods is that the heart of any maturity standard is the minimum level of acceptance of palatability established for mature fruit.

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