6

Maturation and Maturity Indices

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The first step in the postharvest life of the product is the moment of harvest. For most fresh produce, harvest is manual, so the picker is responsible for deciding whether the produce has reached the correct maturity for harvest. The maturity of harvested perishable commodities has an important bearing on their storage life and quality and may affect the way they are handled, transported, and marketed. An understanding of the meaning and measurement of maturity is therefore central to postharvest technology. The meaning of the term *mature*, the importance of maturity determination, and some examples of approaches to determining and applying a satisfactory index of maturity, are discussed in this chapter.

DEFINITION OF MATURITY

To most people *mature* and *ripe* mean the same thing when describing fruit. For example, *mature* is defined in Webster's dictionary as: "mature (fr. L *maturus* ripe):1: Based on slow, careful consideration; 2a (1): having completed natural growth and development: RIPE (2): having undergone maturation, b: having attained a final or desired state; 3a: of or relating to a condition of full development." In postharvest physiology we consider *mature* and *ripe* to be distinct terms for different stages of fruit development (fig. 6.1). *Mature* is best defined by 2a (1) above as "having completed natural growth and development"; for fruits, it is defined in the U.S. Grade standards as "that stage which will ensure proper completion of the ripening process." This latter definition lacks precision in that it fails to define "proper completion of the ripening process." Most postharvest technologists consider that the definition should be "that stage at which a commodity has reached a sufficient stage of development that after harvesting and postharvest handling (including ripening, where required), its quality will be at least the minimum acceptable to the ultimate consumer."

Horticultural maturity is the stage of development at which a plant or plant part possesses the prerequisites for use by consumers for a particular purpose. A given commodity may be horticulturally mature at any stage of development (see fig. 6.1). For example, sprouts or seedlings are horticulturally mature in the early stage of development, whereas most vegetative tissues, flowers, fruits, and underground storage organs become horticulturally mature in the midstage, and seeds and nuts in the late stage, of development. For some commodities, horticultural maturity is reached at more than one stage of development, depending on the desired use of the product. In zucchini squash, for example, the mature product can be the fully open flower, the young fruit, or the fully developed fruit.

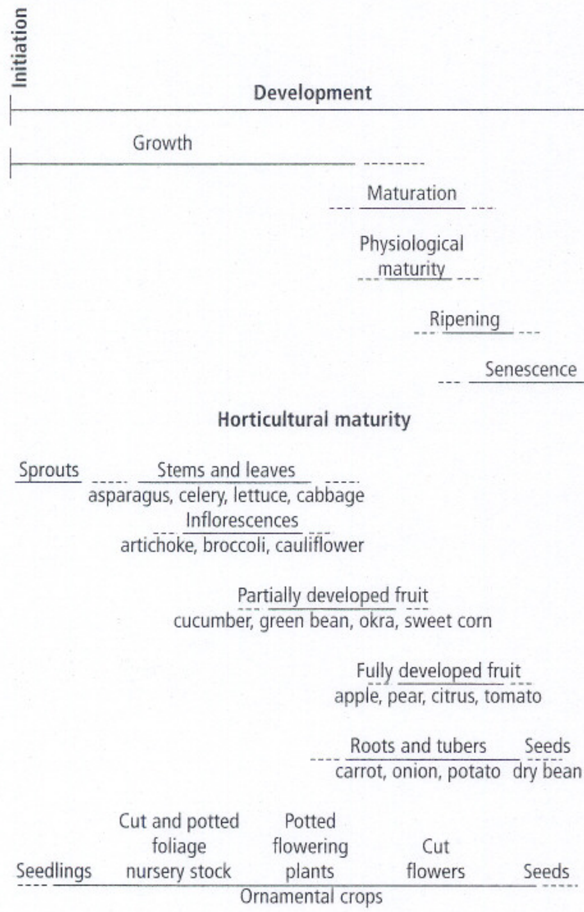
A qualitative difference in the relationship between maturity and edibility distinguishes many fruits from vegetables. In many fruits, such as mature (but green) bananas, the eating quality at maturity will be far less than optimal. The fruit becomes edible only after proper ripening has taken place. In contrast, in most vegetables, optimal maturity coincides with optimal eating quality.

INDICES OF MATURITY

The definition of maturity as the stage of development giving minimum acceptable quality to the ultimate consumer implies a measurable point in the commodity's development, and it also implies the

Figure 6.1

Horticultural maturity in relation to developmental stages of the plant. (Watada et al. 1984)



need for techniques to measure maturity. The maturity index for a commodity is a measurement or measurements that can be used to determine whether a particular example of the commodity is mature. These indices are important to the trade in fresh fruits and vegetables for several reasons.

Trade regulations. Regulations published by grower groups, marketing orders, or legally appointed authorities (such as the state departments of agriculture and the USDA) frequently include a statement of the minimum (and sometimes maximum) maturity acceptable for a given commodity. Objective maturity standards are available for relatively few commodities, and most regulations rely on subjective judgments related to the broad definitions quoted above.

Marketing strategy. In most markets the laws of supply and demand create price incentives for the earliest (or sometimes the latest) shipments of particular commodities. This encourages growers and shippers to expedite or delay harvesting their crop to take advantage of premium prices. The minimum maturity statements in the grade standards exist to prevent the sale of immature or overmature product and the consequent loss of consumer confidence. Objective maturity indices enable growers to know whether their commodity can be harvested when the market is buoyant.

Efficient use of labor resources. With many crops the need for labor and equipment for harvesting and handling is seasonal. In order to plan operations efficiently, growers need to predict the likely starting and finishing dates for the harvest of each commodity. Objective maturity indices are vital for accurate prediction of harvest dates.

CHARACTERISTICS OF A MATURITY INDEX

Maturity measures made by producers, handlers, and quality control personnel must be simple, readily performed in the field or orchard, and require relatively inexpensive equipment. The index should preferably be objective (a measurement) rather than subjective (an evaluation). The index must consistently relate to the quality and postharvest life of the commodity for all growers, districts, and years. If possible, the index should be nondestructive.

The search for an objective determination of maturity has occupied the attention of many horticulturists working with a wide range of commodities for many years. The number of satisfactory indices that have been suggested is nevertheless rather small, and for most commodities the search for a satisfactory maturity index continues.

Two rather different problems will be addressed here. The first problem is how to measure maturity at harvest or at a subsequent inspection point. The second and more complex problem is how to predict the time at which a commodity will mature. For both problems, similar techniques may be appropriate, but the ways in which they are applied differ.

DEVELOPING A MATURITY INDEX

Many features of fruits and vegetables have been used in attempting to provide adequate estimates of maturity. Examples of those that have been proposed, or that are presently in use, are shown in table 6.1. The wide range of methods that have been devised to measure these features are summarized in table 6.2.

The strategy for developing a maturity index is

- To determine changes in the commodity throughout its development.
- To look for a feature (size, color, solidity, etc.) whose changes correlate well with the stages of the commodity's development.
- To use storage trials and organoleptic assays (taste panels) to determine the value (or level) of the maturity index that defines minimum acceptable maturity.

Table 6.1. Maturity indices for selected fruits and vegetables

Index	Examples
Elapsed days from full bloom to harvest	Apples, pears
Mean heat units during development	Peas, apples, sweet corn
Development of abscission layer	Some melons, apples, feijoas
Surface morphology and structure	Cuticle formation on grapes, tomatoes Netting of some melons Gloss of some fruits (development of wax)
Size	All fruits and many vegetables
Specific gravity	Cherries, watermelons, potatoes
Shape	Angularity of banana fingers Full cheeks of mangoes Compactness of broccoli and cauliflower
Solidity	Lettuce, cabbage, Brussels sprouts
Textural properties:	
Firmness	Apples, pears, stone fruits
Tenderness	Peas
External color	All fruits and most vegetables
Internal color and structure	Formation of jellylike material in tomato fruits Flesh color of some fruits
Compositional factors:	
Starch content	Apples, pears
Sugar content	Apples, pears, stone fruits, grapes
Acid content, sugar/acid ratio	Pomegranates, citrus, papaya, melons, kiwifruit
Juice content	Citrus fruits
Oil content	Avocados
Astringency (tannin content)	Persimmons, dates
Internal ethylene concentration	Apples, pears

- When the relationship between changes in the maturity index quantity and the quality and storage life of the commodity has been determined, an index value can be assigned for the minimal acceptable maturity.
- To test the index over several years and in several growing locations to ensure that it consistently reflects the quality of the harvested product.

FEATURES USED AS MATURITY INDICES

Chronological features

For certain crops (fast-rotation vegetables, such as radish, and perennial tree crops growing in short summer environments), maturity can be defined chronologically, for example, as days from planting or as days from flowering. Chronological indices are seldom perfect, but they do permit a degree of planning, and they are widely used. For some crops, the chronological method is refined by calculating heat units accumulated during the growing period, which modulates the chronological index according to the weather pattern during the growing season.

Physical features

A wide range of physical features are used to assess the maturity of various commodities.

Size, shape, and surface characteristics. Changes in the size, shape, or surface characteristics of fruits and vegetables are commonly used as maturity indices. For example, vegetables in particular are harvested when they have reached a marketable size and before they become too large. Maturity in bananas is determined by measuring the diameter of the fingers; changes in the surface gloss or feel (waxiness) are used as a practical tool in harvesting of some melons such as honeydew (see chapter 33, table 33.4).

Abscission. In many fruits, during the later stages of maturation and the start of ripening, a special band of cells, the abscission zone, develops on the stalk (pedicel) that attaches the fruit to the plant. The abscission zone permits the fruit to separate from the plant. Measuring the development of this zone (degree of separation) is possibly the oldest of all maturity indices. Abscission force (the force required to pull the fruit from the tree) is not generally used as a formal maturity index, but the development of the abscission zone, or "slip," in the netted muskmelons (see chapter 33, fig. 33.9) is used to determine their maturity.

Color. The color change that accompanies maturation in many fruits is widely used as a maturity index. Objective measurement of color requires expensive equipment (fig 6.2), and although the human eye is unable to give a good evaluation of a single color, it is extremely sensitive to differences between colors. Color comparison techniques are therefore commonly used to assess fruit maturity (fig 6.3). Color swatches may be used to determine external or internal color. Accurate devices employing state-of-the-art electronics and optics now permit objective color measurements. As the price of such devices has fallen, they have replaced comparison techniques in many cases. For example, digital color examination is now used in the sorting of mechanically harvested processing tomatoes.

Texture. Maturation of fruits is often accompanied by softening; overmature vegetables frequently become fibrous or tough. These textural properties can be used to determine maturity. They are measured with

Table 6.2. Methods of maturity determination

Index	Method of determination	Subjective	Objective	Destructive	Non-destructive
Elapsed days from full bloom	Computation		×		×
Mean heat units	Computation from weather data		×		×
Development of abscission layer	Visual or force of separation	×	×		×
Surface structure	Visual	×			×
Size	Various measuring devices, weight		×		×
Specific gravity	Density gradient solutions, flotation techniques, vol/wt		×		×
Shape	Dimensions, ratio charts	×	×		×
Solidity	Feel, bulk density, gamma rays, X-rays	×	×		×
Textural properties:					
Firmness	Firmness testers, deformation		×	×	
Tenderness	Tenderometer		×	×	
Toughness	Texturometer, fibrometer (also: chemical methods for determination of polysaccharides)		×	×	
Color, external	Light reflectance		×		×
	Visual color charts	×			×
Color, internal	Light transmittance, delayed light emission		×		×
	Visual examination	×		×	
Compositional factors:					
Dry matter	Sampling, drying		×	×	
Starch content	KI test, other chemical tests		×	×	
Sugar content	Hand refractometer, chemical tests		×	×	
Acid content	Titration, chemical tests		×	×	
Juice content	Extraction		×	×	
Oil content	Extraction, chemical tests		×	×	
Tannin content	Ferric chloride test		×	×	
Internal ethylene	Gas chromatography		×	×	×

instruments that measure the force required to push a probe of known diameter through the flesh of the fruit or vegetable (fig 6.4). The solidity of lettuce, cabbage, and Brussels sprouts is an important quality and maturity characteristic. In the case of lettuce, gamma-ray equipment has been devised to measure head firmness, but the technique has not been adopted commercially.

Chemical changes. The maturation of fruits and vegetables is often accompanied by profound changes in their chemical composition. Many of these changes have been used in studies of maturation, but relatively few have provided satisfactory maturity indices because they usually require destructive sampling and complex chemical analysis. Chemical changes that are used for

Figure 6.2

Colorimeter used to measure surface color of apples.

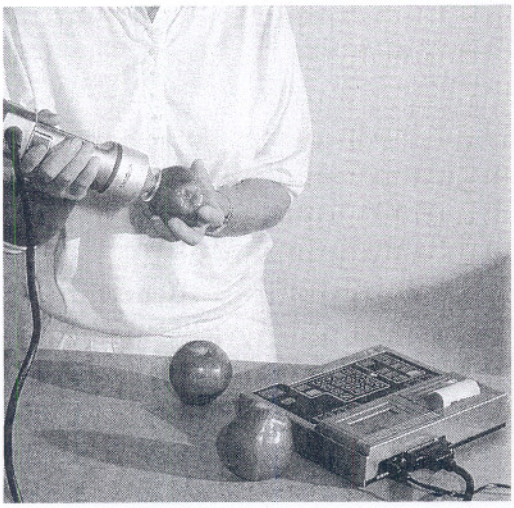


Figure 6.3

Color matching used for maturity grading.

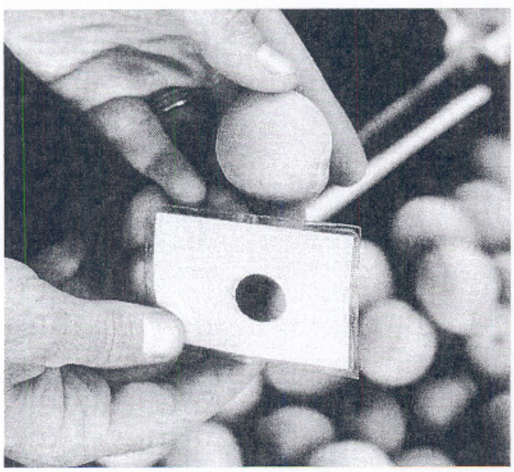


Figure 6.4

Using the UC firmness tester to measure the flesh firmness of apples.

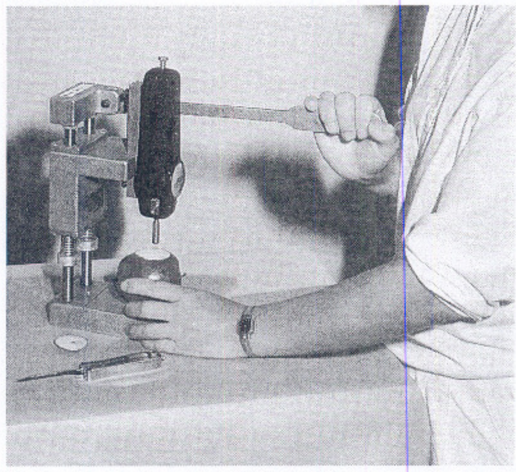


Figure 6.5

Measuring soluble solids content with a refractometer.

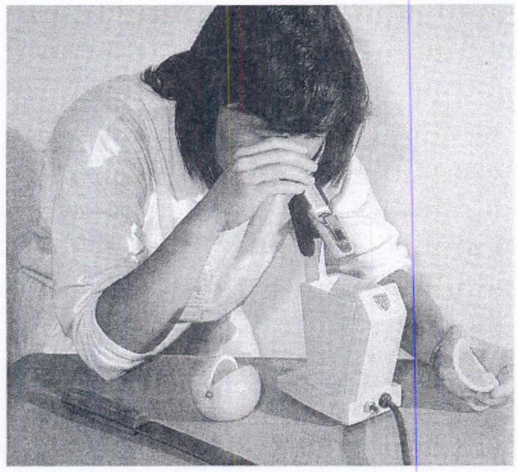
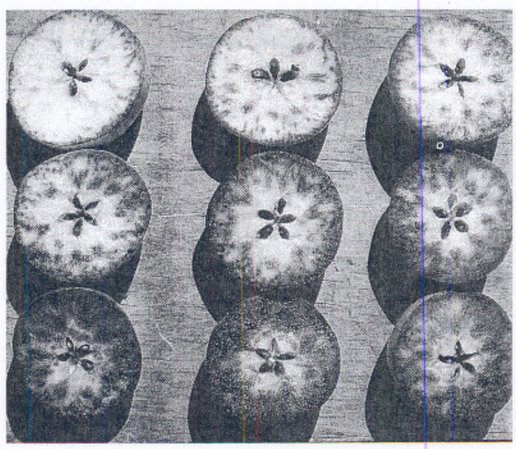


Figure 6.6

Treating cut apples with an iodine solution reveals the disappearance of starch (which stains dark) as apples mature.



maturity estimation include the change in total soluble solids, measured using a refractometer (fig. 6.5); changes in the distribution of starch in the flesh of the commodity, measured using a starch-iodine reaction (fig. 6.6); acidity, determined by titration; and the sugar to acid ratio, which is used as the legal maturity index for citrus.

The unsatisfactory nature of chemical tests for maturity is exemplified by the old oil content measurement for avocados, which has been replaced by the determination of percent dry weight because of the time-consuming and complex nature of oil determination.

French scientists have developed an interesting approach to objective maturity (and quality) determination of harvested melons; they remove a slender cylinder of flesh from each melon and rapidly determine its sugar content by measuring the refractive index of the juice. The outer portion of the cylinder is replaced, and the melon is accepted or rejected based on the sugar reading.

New opportunities in chemical analysis are exemplified by the development of near-infrared technologies for examining the composition of fruits and vegetables, and rapid sensor technology for determining volatile profiles in harvested products. The former is able to measure sugars in fruits nondestructively, and the latter is sufficiently rapid to enable determination of melon maturity in the field. Researchers have found, for example, that the sugar content of peaches can be accurately determined using near-infrared absorption profiles. As melons mature, their production of aroma volatiles increases dramatically. An instrument has been developed that enables this increased production to be an indicator of harvest readiness.

Physiological changes. The maturation of commodities is associated with changes in their physiology, as measured by changing patterns of respiration and ethylene production. The problem with using these characteristics in assessing maturity is the variability in absolute rates of ethylene production and respiration among similar individuals of the same commodity. The techniques are also complex and expensive to implement on a commercial scale. Nevertheless, the rate of ethylene production of a sample of apples is used by some producers to establish the maturity of the apples, and it is particularly used to identify those that will be suited to long-term controlled atmosphere storage.

PREDICTING MATURITY

Predicting when a commodity will mature is more complex than assessing its maturity at or after harvest. The basic requirement for prediction is a measurement whose change during the commodity's development can be modeled mathematically to reveal a pattern or patterns of change. Once the pattern of change is established for the measurement, measurements made early in the season can be compared with the pattern in order to predict the date at which the commodity should reach minimum acceptable maturity. The way in which this strategy has been applied can best be illustrated by the following examples.

APPLES

Although the literature on the prediction of maturity in apples is voluminous, no truly satisfactory method has yet been proposed. The use of climatic data to predict the date of harvest by a modification of the "days from full bloom" index noted in table 6.1, even when adapted by using "days from the 'T' stage" has provided only general predictions of the harvest date.

In an attempt to provide a more satisfactory prediction of the maturation date, researchers have examined a number of changes that occur during fruit development. Measurement of respiration, ethylene production, sugar content, starch content, and the changing firmness of fruit each failed to meet some of the criteria for a satisfactory maturity index, and they proved to be too variable to permit prediction of maturation date. The "starch pattern," an old method of determining apple maturity, refined by assigning scores to a range of patterns, has proved to be a good index. Changes in the mean starch index score during the period prior to harvest are readily analyzed as a linear regression, and the date of minimal acceptable maturity and can be predicted several weeks in advance (fig. 6.7).

AVOCADOS

The State of California for many years promulgated a minimum oil content as the maturity standard for avocados. This index has been unsatisfactory, since it is difficult to apply and because some avocados that have more than the minimum oil requirement may be lacking in flavor quality. However, raising the minimum oil content might eliminate from the market particular avocado varieties whose flavor quality is adequate at a low oil content. Using taste panel evaluations to determine quality, researchers have shown that the patterns of dry weight accumulation, or the growth of avocado fruit, can be used not only to determine when minimum acceptable maturity has been achieved but also to predict the date when it will be achieved (fig 6.8). Taste panel scores increased as oil content increased, and oil

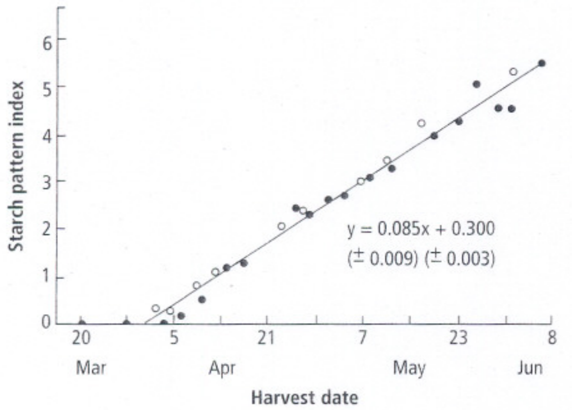


Figure 6.7

Change in starch index values for maturing Granny Smith apples.

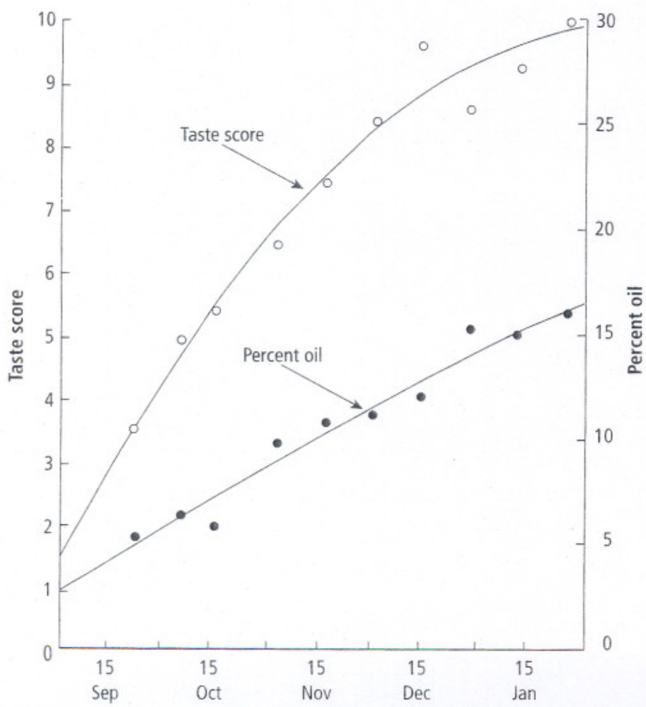


Figure 6.8

Changing acceptability and oil content of maturing avocados. (Lee and Young 1983)

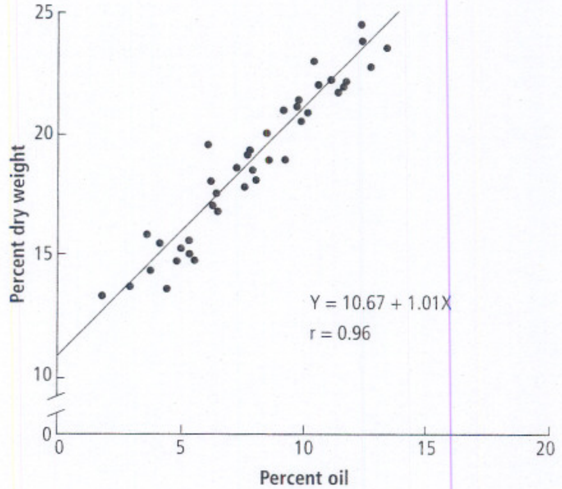


Figure 6.9

Relationship between dry weight and oil content of avocado. (Lee et al. 1983)

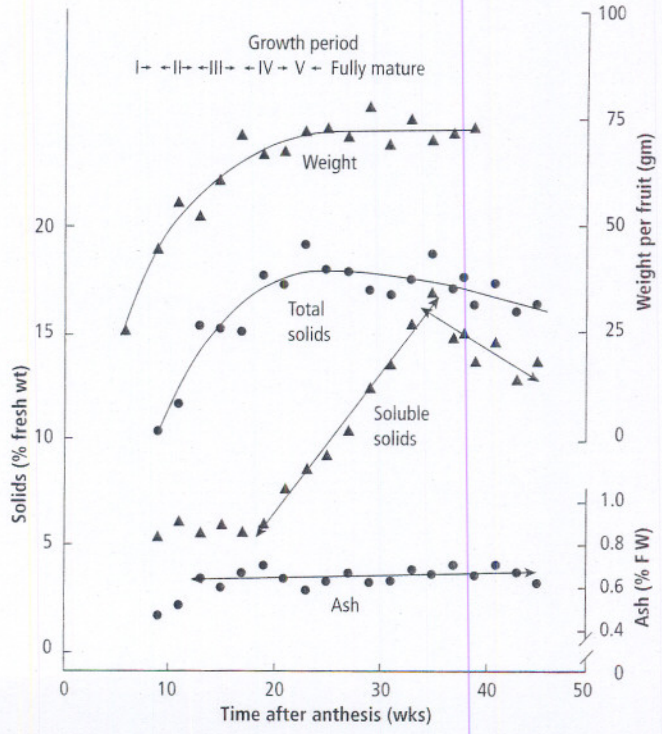


Figure 6.10

Changes in selected chemical and physical parameters of kiwifruit during growth and development.

content was found to be closely correlated with the percent dry weight (fig 6.9). Consequently, the California minimum maturity index was changed from oil content to percent dry weight.

KIWIFRUIT

As a prelude to developing a maturity index for kiwifruit, researchers measured changes in a wide range of chemical and physical characteristics during growth and development (fig. 6.10). This information was compared to storage life and taste panel results to decide on possible methods for determining, and if possible predicting, the time of minimal acceptable maturity for this crop. It seemed possible that soluble solids content and fruit firmness might provide a suitable maturity index, but in repeating the experiments over several seasons, changes in the firmness of the fruit were found to be highly variable and unrelated to fruit quality (fig. 6.11). In New Zealand, a minimum maturity index of 6.25% soluble solids has now been used for many years. The change in soluble solids in the 6 weeks prior to the normal harvest date can be used, with regression analysis, to predict the date of harvest for different orchards, seasons, and growing districts (fig. 6.12).

Figure 6.11

Changes in fruit firmness during maturation of kiwifruit.

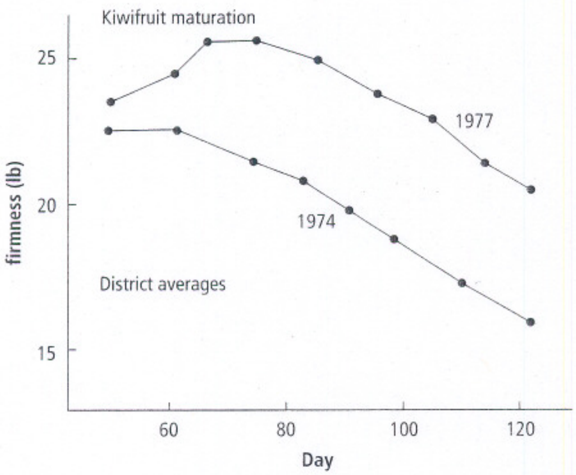
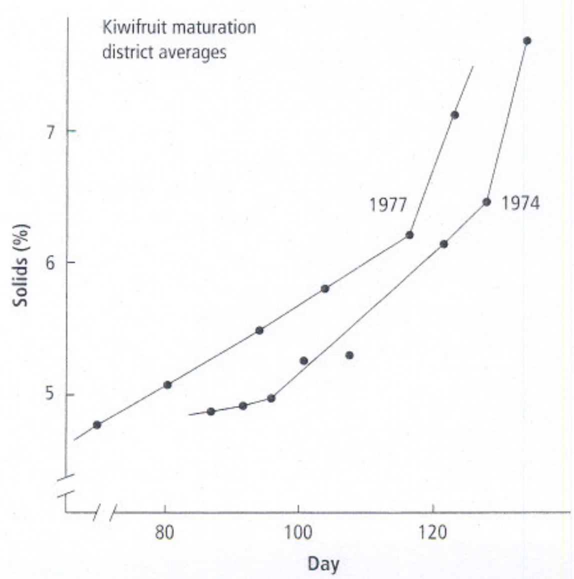


Figure 6.12

Changes in soluble solids content during the 6 weeks before harvest of kiwifruit can be used to predict harvest date.



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