CHAPTER

5

Harvesting of Horticultural Commodities

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5.1 INTRODUCTION

Depending on the country of production, there are 10%–40% of losses in horticultural crops between harvesting and consumption. These losses may occur during different stages of postharvest operations including harvesting, handling, packing, storing, shipping, marketing, and consumption. The main aim of postharvest operations is to minimize these losses; harvest maturity is the first important phase that affects these losses. Besides quantity, nutritional (loss of vitamins, antioxidants, and health-promoting substances) and/or value losses are other important losses that take place in fresh produce during postharvest operations. Therefore, horticultural commodities require careful handling right from the harvesting to every stage of postharvest operations for reducing losses and maintaining high fruit quality.

The lifespan of the horticultural products can be divided into two parts; preharvest and postharvest stages. The first step in the postharvest phase starts with harvesting at the orchard and continues in various storage/packing house and marketing operations. There are many postharvest factors affecting the quality of fresh produce, but one of the most important ones is the determination of harvest maturity. Furthermore, all horticultural crops must be harvested at the most appropriate maturity stage in order to achieve consumer satisfaction and repeated purchases.

Fruits and vegetables must be harvested properly to reduce damage caused by harvesting, as most postharvest damage occurs due to inappropriate handling at harvest. Harvesting affects the quality of product and the quantity of postharvest losses during packaging, storage, shipping, and marketing.

Fruit development stages in horticultural crops include fruit set, cell division, cell enlargement, maturation, ripening, senescence, and death. Fruit development is a consequence of cell division and cell enlargement that results in an increase of fruit size including width, height,

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weight, and volume. When the physical development and harvest maturity of the fruit are completed, fruit is ready to be harvested. Some physiological processes such as respiration continue even though they are at a reduced level during senescence, which is the last stage of fruit development. After senescence, horticultural products deteriorate in the death stage, thus all the physiological reactions in the fruit are ended (Fig. 5.1).

5.2 MATURITY AND HARVESTING

Harvest maturity is one of the most important factors that influence postharvest life and the final quality of products, such as appearance, texture, taste, flavor, and nutritional value. The word "maturity" means "fully developed." The word “mature” is derived from the Latin word "maturus" meaning “maturation.” When the maturation is completed, fruit reaches the harvesting stage. In general, maturation can be accomplished when the crop is on the tree or on the plant, and in some cases maturation can continue even after the fruit has been detached

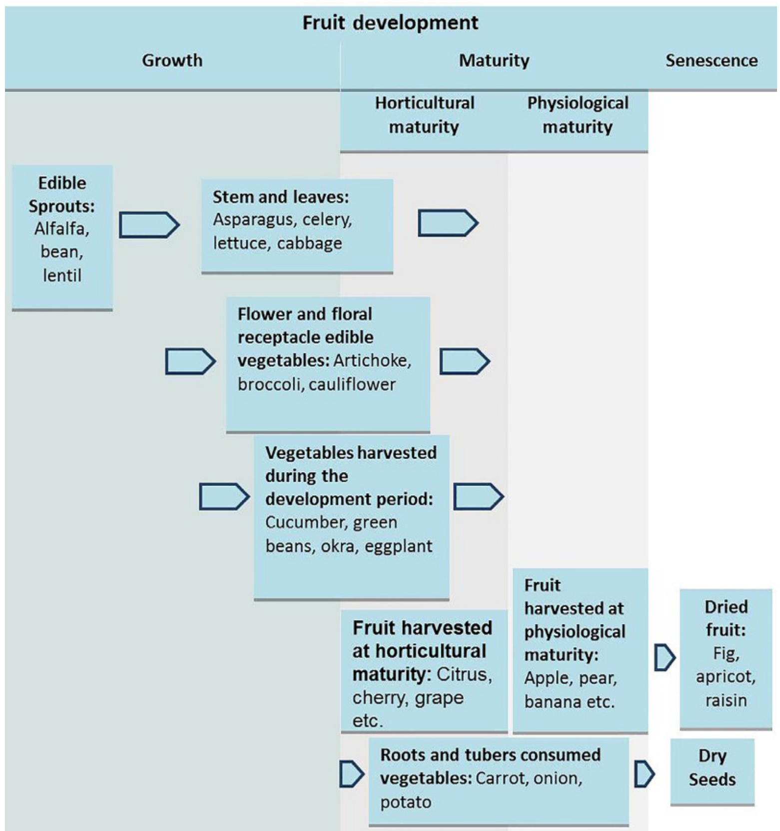

FIG. 5.1 Harvest stages of horticultural crops. (*modified from Watkins and Nock, 2012*)

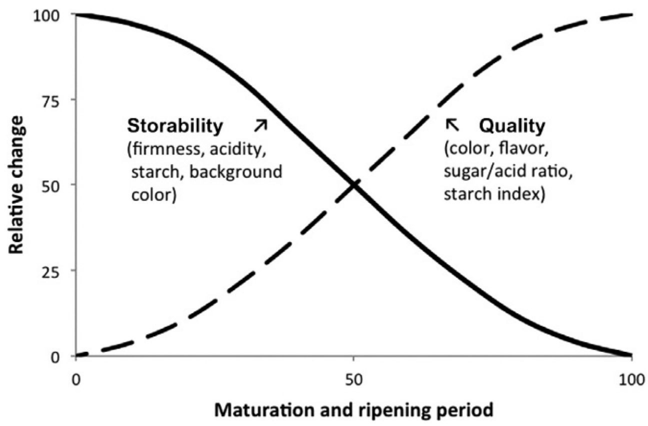

FIG. 5.2 The relationship between the storability and quality in fruit and vegetables (Watkins and Nock, 2012).

from the tree or plant. In general, as fruit ripens, quality attributes such as color and flavor increase, but storability declines (Fig. 5.2). For this reason, it is crucial to determine the correct harvest maturity stage in such fruits that can be ripened after harvest.

5.2.1 Definition of Maturity

Maturation is a sign of fruit ready to harvest. At this point the edible part of the fruit or vegetable is fully developed in shape and size, even though it may not be ready for immediate consumption. In most cases, ripening follows or overlaps with maturation and the produce becomes edible. The term "maturation" has different stages, including immature, mature, fully mature, and over mature. The quality and nutrient status of horticultural crops vary depending on their maturity levels. For example, anthocyanin concentrations of fully matured red strawberries are usually higher than that of white tip (immature) strawberries, while total flavonoids, phenolics, and total antioxidant activities of fruit harvested at the white tip stage are usually greater than those harvested at the red ripe stage. In addition the harvest of immature fruits will result in reduced size and yield, poor quality, and uneven ripening. Generally a compromise between an earlier and a late harvest has to be reached to achieve the premium quality for the consumer and in the same time extend postharvest life for marketing.

The word "ripe" is derived from Saxon word *rip*i, which means "to gather or reap." This is the condition of maximum edible quality attained by the fruit. Ripening is a consequence of biochemical processes, which transform a physiologically mature but inedible fruit into an edible one. Ripening involves a series of changes occurring during the early stages of senescence, in which structure and composition of unripe fruit is so altered that it becomes acceptable to eat. Ripening is a process resulting in softening, coloring, and sweetening as well as an increase in aroma compounds that make fruit ready to be consumed or processed. Some fruits need to ripen for consumer acceptance after harvest.

Senescence is the last stage of postharvest phase before death, and it is characterized by natural degradation, loss of texture, flavor, and other quality parameters.

The maturity of a fruit/vegetable can be considered in two different parts: *physiological maturity* and *horticultural maturity*.

Physiological maturity: refers to the stage of development where a fruit/vegetable can continue with the developmental processes even after being detached from the parent plant.

Horticultural maturity: refers to the stage of development in which a fruit/vegetable possesses the prerequisites for use by consumers. It is sometimes referred to as commercial maturity.

The maturity of a fruit or vegetable at harvest, whether physiological or horticultural, is a very important factor that determines the storage life as well as the final quality of the product.

5.2.2 Determination of Maturity

The determination of harvest time is based on a compromise between flexibility in marketing and the best eating quality for the consumer. In some cases, if the produce has to be shipped to distant markets or stored for a better price, it should be harvested in the mature but unripe stage. We always keep in mind that fruits and vegetables reach the best quality at harvest, but quality after harvest cannot be improved but only maintained. Therefore harvest maturity is the key factor of success for long-term storage, consumer satisfaction, and marketing.

A number of biochemical changes take place during maturity and ripening. These include:

- Changes in carbohydrate composition, resulting in sugar accumulation and increasing fruit sweetness.
- Changes in either fruit skin or ground color due to changes in pigments such as chlorophylls, carotenoids, anthocyanins, and betalaines.
- Flesh softening and textural changes due to cell wall degradation.
- Accumulation of aroma volatiles.
- Loss of acids and astringent substances.
- Increases in ethylene production and respiration rate in climacteric fruits and vegetables.

Importance of maturity indices:

- To obtain maximum sensory and nutritional quality
- To obtain prolonged storage and shelf life capacity
- To facilitate scheduling of harvest window and packinghouse operations
- To manage shipping and marketing

Extensive research has been conducted to determine the optimum maturity parameters for many horticultural crops. Maturity must be defined for each species and in some cases for each cultivar. The use of different maturity parameters for each crop provides to consumers premium quality fruit and vegetables. Another reason for establishing maturity standards is that most horticultural products are harvested by hand. Thus, maturity standards can help pickers to harvest crops at the correct developmental stage. Although numerous methods have been developed and tested for determining optimum harvest maturity, no single method has proven solely adequate for evaluating the harvest maturity. Combining several indices should be advantageous to a single method, as each parameter provides information about the physiological stage of the fruit and collectively should reduce fruit-to-fruit, seasonal, and location-related variability.

Fruits and vegetables are consumed at different stages of development. Vegetables are harvested at different physiological stages depending on the plant part to be used during consumption. In some cases, vegetables are picked before the fruit is formed, developed, or fully matured. Some vegetables such as eggplants and cucumbers are not suitable for fresh consumption when they reach the over maturity stage on the plant. Some vegetables are harvested before they reach maturity stage, such as the case for green bell pepper, cucumber, summer squash, beans, okra, and eggplant. These vegetables reach the best eating quality before the fully mature stage, and delaying harvest results in lower quality at harvest and faster deterioration rates after harvest. In contrast, some fruits and vegetables such as tomatoes, red peppers, melons, watermelons, and pumpkins can reach the best eating quality at the mature stage. In some cases the necessity of shipping mature fruits and vegetables to long-distance markets encourage harvesting them at less than optimal maturity, resulting in inferior taste and quality to the consumers, and fruit may never ripen after reaching destination. There are disadvantages of early and late harvest.

Disadvantages of early harvest:

- Early harvested fruits and vegetables may not reach their final optimal size, shape, or weight due to uncompleted fruit development, which may result in low yields.
- In early harvested fruits, carbohydrates and primarily sugar accumulation, loss of acid and astringent substances, cell wall degradation and the formation of aroma substances may not enough. Even if these fruits ripened after harvest, they may not reach a good texture, taste, or flavor, resulting in low consumer satisfaction.
- Fruits and vegetables harvested early may not develop the desired skin color. For this reason the external quality and consumer demand are lowered.
- Cuticular and lenticular development may not be completed in early harvested fruits, so weight loss due to water loss could be high and these fruits can wrinkle quickly.
- Early harvested fruits and vegetables may become prone to some physiological disorders.

Disadvantages of late harvest:

- The storage duration of late harvested fruit is relatively shorter than those harvested at optimal maturity stages, mostly due to sensitivity to mechanical harvest damage and rough postharvest handling.
- These fruits are more prone to fungal decay, especially those over mature.
- The fruit taste may become inferior due to different factors, such as severe reduction in acidity and flavor.
- These fruits may become susceptible to some physiological disorders.
- Late harvest increases preharvest fruit drop and ends up with a reduced yield (Fig. 5.3).

5.2.3 Maturity and Harvesting Indices

The common methods used for optimal maturity and harvesting time determinations are based on either subjective or objective parameters. Different methods including sight, touch,

FIG. 5.3 Severe preharvest drop in apples (left) and cracking in pomegranate fruits due to late harvest (right).

smell, and biochemical and morphological changes can be used to achieve this goal. Furthermore, chemical, physical analyses, computation, and nondestructive techniques are also used as guides for harvest maturity. While some of these indices are imperative and used for almost all horticultural crops, other methods give a general idea and are used only for specific crops. For example, color is a general maturity index for almost all crops; however, slip in melons, hull splitting in walnuts and almonds, astringency in persimmon, and oil content in avocado are specific parameters. A combination of all these parameters that is appropriate for each horticultural crop reduces the chance of making mistakes in determining the optimal harvest time. Generally, objective maturity parameters are recommended over the subjective ones. In practice the most commonly used maturity indices include fruit size, skin and flesh color, fruit firmness, total soluble solids (TSS) content, iodine test for starch content, and titratable acidity (TA). Many of these parameters that are used for qualitative attributes of the crop may also be used to determine its postharvest quality. Maturity and harvesting indices should be measurable, simple, and readily performed in orchards or packing houses. They should be achievable by inexpensive equipment, nondestructive, objective, and consistently related to the quality parameters of the commodity.

Types of indices and their components:

- Visual indices: size, shape, color, and hull splitting.
- Physical indices: firmness, juice yield, and specific gravity.
- Chemical indices: TSS, TA, iodine test for starch content, astringency.
- Calculated indices: calendar date, heat units (growing degree days).
- Nondestructive indices: DA (Delta absorbance) meter.

5.2.3.1 *Skin/Fruit Color*

The changes in skin or fruit color are the clearest signals of maturity and harvesting time. Color is a basic parameter for determining the harvesting time for many horticultural crops. In most cases, consumers can only decide whether the fruit is ripe or unripe just by looking at its skin color. It relates directly to consumer perception in terms of appearance and appeal (Fig. 5.4). The skin or flesh color of most fruits and vegetables changes as the fruit approach

FIG. 5.4 Skin color is a good maturity indices for sweet cherry (left) and aril color for pomegranate fruit (right).

maturity or ripening. In most cases, these visual changes can be subjectively determined. However, color charts and colorimeters (Fig. 5.5) have been developed for determining optimal harvesting time of different fruits and vegetables. Some fruits such as citrus do not exhibit a relationship between peel color and maturity, and therefore this parameter is not ideal to be used as an indication of harvest maturity.

As fruit matures, several changes take place in skin color from green to red, yellow, or other color. This is due to the continuous degradation of chlorophylls and the development of other pigment(s). As chlorophylls break down other color pigments such as carotenoids, betalaines and anthocyanins become more pronounced and other colors appear on the skin surface. Color charts prepared for this purpose are used in the determination of skin color, but they need to be prepared separately for each species and cultivar. In some fruits, there may be no discoloration of the ground color at harvesting time; such is the case in Granny Smith apples, bananas, and avocados. In these fruits the dark green skin color of the fruit generally turns into a light green color at harvest.

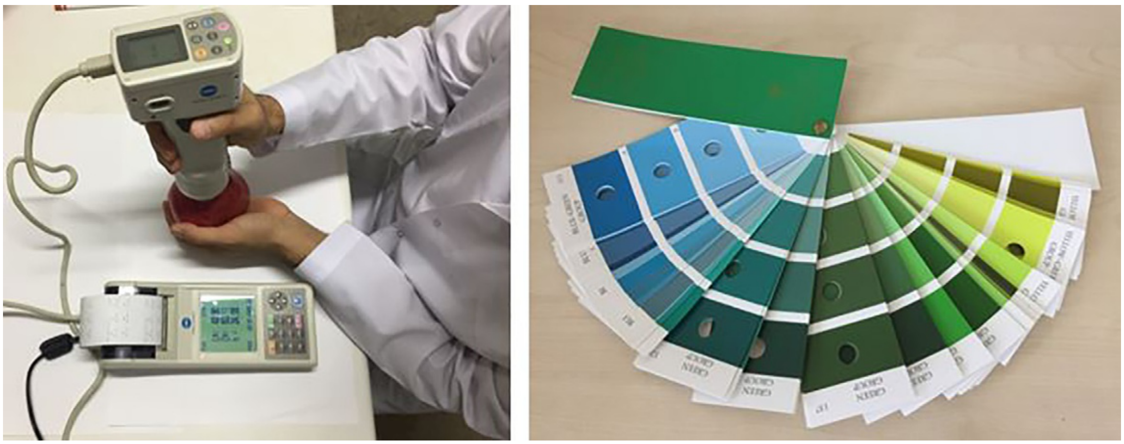

FIG. 5.5 Fruit color can be measured by colorimeter and color charts.

The skin color of fruits and vegetables usually contain carotenoids, anthocyanins, or betalaines when they mature. These pigments give fruit a yellow, orange, or red to purplish-blackish color, and this coloration can be successfully used in determining maturity and harvesting time. In red-skinned apples, as the fruit matures the skin color turns red by increasing anthocyanin content; for proper coloring, sunlight is important. Thus in apples the fruit on the outer part of the trees are more reddish comparing to the fruit located in inner parts of the trees. However, plums, cherries, and some grapes form a red color without having much direct sunlight. In most cases, carotenoids (yellow, orange, and red colors) or flavonoids/anthocyanins (red and blue colors) or betalaines (yellow and red colors) are responsible for color changes during maturation.

Fruit color can be determined subjectively or objectively by colorimeters. For example, in red-skinned apples, it is desirable for consumer appealing to have at least 55%–60% and generally 85%–90% of the red color of the fruit skin development at harvest. In the objective method, color space is defined by the CIE, based on one channel for luminance (lightness) (L^*) and two colors channels (a and b). Minolta and Hunter colorimeters are the most common color measuring devices used. In this method the color differences correspond to intensity. The "a" axis extends from green ($-a$) to red ($+a$) and the b axis from blue ($-b$) to yellow ($+b$). The lightness (L^*) increases from the bottom to the top indicating $L^* = 0$ (black) and 100 (white). Chroma (C^*) values (0 = matte, 60 saturation) indicate color saturation; the zero value of C^* is a completely neutral color. Hue angle ($h°$) is the coordinate (0° = red, 90° = yellow, 180° = green and 270° = blue). C^* and $h°$ values can be calculated as given below:

$$C^* = \sqrt{a^{*2} + b^{*2}}$$

$$h° = \tan^{-1}(b^*/a^*)$$

5.2.3.2 Seed Color

In papayas, apples, and pear fruits, maturity can be estimated by changes in the seed color. In practice, some apple and pear growers use the change in seed color from white to brown for harvesting time. However, in most cases a dark seed color is usually a sign that fruits are ripe and ready to be consumed. Therefore, it is a poor indication of maturity when harvested fruit is intended for long-term storage.

5.2.3.3 Fruit Firmness

During maturation and ripening, protopectin is gradually degraded into lower molecular weight fractions, which are more soluble in water. The rate of pectin degradation is directly correlated to the softening rate of the fruit. The degradation of pectin substances is linked to increased soluble polyuronides and decreased insoluble polyuronides. In some fruits, this textural change can be used as a useful tool for determining harvest maturity. Fruit firmness is detected subjectively by touching or gentle squeezing the fruit. However, objective measurement can be achieved by using penetrometers and texture analyzers (Fig. 5.6). During maturity the fruits soften as the pectic substances break down. Fruit softening is influenced by a several factors and is not always related to physiological maturity. Climatic conditions affect softening. For example, if the maturation season is cooler than usual, softening occurs slowly. If a hot period lasts for a few days and is followed by a cool period, then the softening

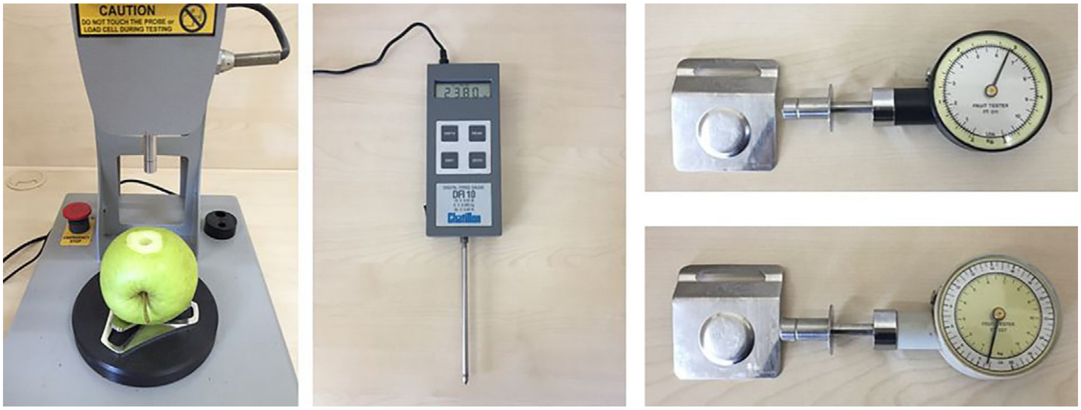

FIG. 5.6 Measuring fruit firmness in apples and different types of penetrometers.

of the fruit will accelerate. The soil humidity and nitrogen level in the soil and calcium level in the fruit also affect softening. Rootstocks also have an impact on fruit softening. Fruit size is another important factor affecting firmness, and in general, larger fruit is softer than smaller fruit.

For objective firmness measurements using penetrometers and texture analyzers, 1 cm^2 fruit skin surface from the equatorial region on two or three sides of the fruits is removed with a specially designed sharp knife. The depth of the cut removing influences the reading: the deeper the cut, the higher the reading. Then the firmness measurement is conducted. For a correct measurement the fruit should be placed on a hard surface rather than being held in the hand. Furthermore, the plunger should be inserted to the line inscribed on the plunger. The resistance of fruit to penetration force applied by a penetrometer is determined and firmness is measured as Newton (N), kg-force (kg-f) or pound force units. For this purpose, different plungers or probes are used depending on fruit types, such as an 8 mm (5/16 in.) plunger used for pears, stone fruits, and kiwifruit or a 11 mm (7/16 in.) plunger used for apples. Flesh firmness is one of the most important maturity indices for many horticultural products, especially apples, pears, and stone fruits.

5.2.3.4 Heat Units

The time required for fruits to reach maturity can be determined by using the total amount of heat received and can be expressed as degree days or heat units. This method can be used for maturity determination in some products such as apples, pears, and table grapes. The number of degree days to maturity is determined over a period of several years by obtaining the algebraic sum of the differences, plus or minus between the daily mean temperature. The average or characteristic number of degree days is then used to forecast the probable date of maturity for the current year. The heat units required for a growing area can be calculated as follows:

$$H = T - TL \times D$$

H is the heat units or degree days; T is the mean or average monthly temperature; TL is the baseline temperature; and D is the number of days in month.

5.2.3.5 *Specific Gravity*

Specific gravity can be used for the determination of maturity and harvesting time in some commodities such as guava, cherries, and mango. Fruits that float on water have low TSS and low specific gravity and are hence immature, while fruits that sink in water have specific gravity more than "1" and are therefore mature.

5.2.3.6 *Starch-Iodine Test*

As the fruit reach the maturity stage, carbohydrate polymers degrade and starch is converted into sugar. This soluble carbohydrate affects both the taste and the texture of the fruit, and so the fruit become sweeter and softer. The use of this maturity parameter is a good indication of maturity in some fruits such as apples, pears, and quince. When maturation starts, starch breaks down into sugar from the fruit core to outer flesh. The conversion of starch to sugars is related to the maturity and varies from fruit to fruit and from year to year. Thus a specific scale showing this conversion can be arranged for each species and cultivar. Excessive crop load on the tree reduces the amount of starch in fruit and can lead to a poor interpretation of the starch-iodine test. Starch accumulation starts from epidermis to core while degradation starts from core towards to the epidermis. This degradation can be monitored by potassium iodine solution (I_2KI). When I_2KI reacts with starch a bluish gray color can be seen on the fleshy areas of the fruit (Fig. 5.7). For this purpose the fruit is cut into two pieces from the equatorial region, immersed in the iodine solution, and left for 30–60 s. Then the stained areas are checked and evaluated against a prepared chart for the type of fruit. Stained areas that are rich in starch are not converted into sugar yet (immature). Regions that have unstained areas contain converted sugar (mature or ripe). There are different starch-iodide scales such as 1–5, 1–8, or 1–10 for a given cultivar. The lower the value, the lesser the degree of maturity. For example, the Cornell University generic starch-iodine index chart for apples is 1–8 and the harvest window for CA storage of McIntosh apples is usually between 2.8 and 3.5 (Fig. 5.7).

5.2.3.7 *Juice Content*

As the fruit matures the amount of juice in some fruit and vegetables increases. However, juice content shows variation among different varieties and years and even within a single

FIG. 5.7 Starch-iodine index chart for McIntosh apples developed by Cornell University (left) and staining areas in apples (right).

fruit. This parameter is particularly important for determining the harvest maturity of citrus and other processed fruits for juice production. For example, according to the *Turkish* Standards Institution (TSE), lemon fruits at harvest must contain at least 20% juice for export.

5.2.3.8 Total Soluble Solids Content

During maturation the TSS content of the fruits and vegetables increases, and this parameter can be used as a maturity index for some crops. In general the sweetness of fruits having high TSS content is superior to the one having low TSS content. The amount of TSS in the fruit is closely related to climate, nutrition regime, and other cultural practices. Similarly, moisture and nitrogen levels of the soil, fruit load, and photosynthesis capacity of the trees have an impact on the TSS content of the fruit. TSS content is measured as percentage (%) or °Brix with hand or digital refractometers (Fig. 5.8) and can be successfully used for determining harvesting time and harvest maturity of some horticultural crops including apples, pears, stone fruits, grapes, citrus, pomegranates, kiwis, papayas, and melons.

5.2.3.9 Streif Index

TSS content and flesh firmness are both affected by ecology and cultural practices. Therefore it is not possible to judge the harvesting time correctly by using only one parameter. Using the combination of flesh firmness, TSS content, and starch index, which is called the Streif index or ripening index, gives a much more accurate results, particularly for fruits with high starch content, such as apples and pears. The Streif index is calculated according to the following equation:

$$\text{Streif index} = \frac{\text{Flesh firmness}}{\text{TSS} \times \text{starch index}}$$

The Streif index should be in the range 0.9–1.1, and it should not be lower than 0.8 at harvest.

5.2.3.10 Titratable Acidity

TA in fruits and vegetables gradually decreases during maturation and ripening. Climate and cultural practices influence acid contents of horticultural crops. However, it can be misleading to decide the harvest time by using only the acidity level of the produce; it should be combined with other maturity indices. TA is an important parameter in determining the maturity of apples, pears, stone fruits, grapes, pomegranates, and citrus fruits. TA is the percent (%) acidity level of the fruit and is determined by an acid-base titration and expressed in terms

FIG. 5.8 Hand and digital refractometers.

of the predominant type of acid. TA is determined by titration method using sodium hydroxide (NaOH) solution and phenolphthalein indicator or a pH meter. For this purpose, 2 or 5 mL of juice from the fruit are taken and diluted with 50 mL of purified water. Then the diluted sample is titrated to pH 8.1 with 0.1 N NaOH solution using a pH meter or phenolphthalein indicator (slightly pink color indicates the end of the titration). Some fruits may contain more than one type of acid, but during the titration the primary acid is considered only. Important acids and their multiplication factors used in acidity calculation formula are given below.

Factor for:

Citric acid: 0.0064 (Citrus fruits, berries, pomegranates, tomatoes)
Malic acid: 0.0067 (Apples, pears, peaches, nectarines)
Tartaric acid: 0.0075 (Grapes)

For citric acid, 1 mL of 0.1M NaOH is equivalent to 0.0064 g of citric acid.

The dominant organic acid is calculated according to the following formula:

$$TA^{*} = \frac{\text{mL NaOH} \times \text{N(NaOH)} \times \text{acid meq.Factor} \times 100}{\text{mL juice titrated}}$$

*Results expressed as percentage acidity.

$$TA^{**} = \frac{\text{mL NaOH} \times \text{N(NaOH)} \times \text{acid meq.Factor} \times 100 \times 100}{\text{mL juice titrated}}$$

**Results expressed as acidity in g/L.

5.2.3.11 TSS/TA Ratio

Consumer preference of fruit and vegetable consumption is directly related to an acceptable amount of sugar/acid balance. Therefore the ratio of TSS/TA can be used to determine the harvest time of some commodities, whereas the maturity index is an expression of the relationship between the sugar and acid contents. It gives a much more reliable measurement for palatability compared to the sugar content or acidity alone. The ratio can be obtained by dividing the ^{o}Brix or TSS by the total acidity (TSS/TA). TSS/TA ratio of citrus fruit at harvest are given in Table 5.1. This index is mainly used for grapes, pomegranates, and citrus fruits and to a lesser extent for apples, pears, stone fruits, papayas, and melons. The TSS/TA ratios of citrus fruits for export of some countries are given in Table 5.2.

5.2.3.12 Fruit Shape and Size

The shape of fruit may change during maturation and can be used to determine harvest maturity in some fruits. Size increases as fresh produce approaches maturity (Fig. 5.9). For example the size of broccoli florets, cauliflower curd, and cabbage heads increases until full maturity. Similarly, banana fingers become more rounded in cross-sections as they develop on the plant. Mangoes also change their shape during maturation. As mango fruit matures the ratio between the shoulder and stalk attachment point of fruit may be changed (Fig. 5.9). Stone fruits are also considered mature when fruit shoulders are well developed and filled out. The size and shape of fruit and vegetables are affected by cultivar, temperature, and crop load. In sweet cherries, as fruit increases in size the color turns from light red to dark red (Fig. 5.10).

TABLE 5.1 The Main Maturity Indices for Citrus[a] (Lado et al., 2014: Please Note That the Publisher Will Require Permission to Include Data Published By Others)

Citrus Types	TSS (%)	TA (%)	TSS:TA Ratio	Juice (%)
Oranges	8	0.4–0.7	8–10	>33
Navel oranges			8–8.5	>33
Blood oranges			7	>30
Others				>35
Mandarins	>8–8.5	0.3–0.5	6.5–7.5	
Satsumas			6.5	>33
Clementines			7	>40
Hybrids/others			7.5	
Lemons				>20
Grapefruits	6–7		5.5–7	>35

[a] *Based on EU, California, and Florida standards, TSS: total soluble solids, TA: titratable acidity.*

TABLE 5.2 The Main Maturity Indices Required for the Export of Citrus Produced in Argentina, South Africa, and Uruguay (Lado et al., 2014)

Citrus Types	TSS (%)	TA (%)	TSS:TA Ratio	Juice (%)
Oranges	8.5–9	0.6–1.4	6–9:1[a]	>40–45
Navel oranges			8–8.5	>40–45
Blood oranges			7	
Others				
Mandarins	>8–9	0.65–1.2	7–8	35–48[b]
Satsumas	8		7	>40
Clementines	9		S	>40
Hybrids/others			7–8	
Lemons				>35–36
Grapefruits	7–9[c]	0.6–1.4	5.5–7[d]	>40–45

[a] *The minimum orange ratio 6:1 in Argentina, 7:1 in South Africa, and 9.1 in Uruguay.*
[b] *A minimum juice content of 35% is required for mandarins in Argentina, 40% in Uruguay, and 48% in South Africa.*
[c] *In South Africa a minimum of 7 °Brix is required for yellow grapefruits. In Uruguay a minimum of 8 for yellow and 9 for pink and red grapefruits.*
[d] *The ratio should be at least 5.5:1 in South Africa, 6:1 for yellow and 7:1 for pink and red grapefruits in Uruguay.*

5.2.3.13 Development of Abscission Layer

The fully developed abscission layer around the stalk is a sign of maturity in some fruits and vegetables. Abscission occurs after the formation of an abscission zone at the point of separation. During abscission zone formation, there is specific enzymatic activity that reduces auxins and increases cell wall and membrane degradation. The abscission zone is a thin cell

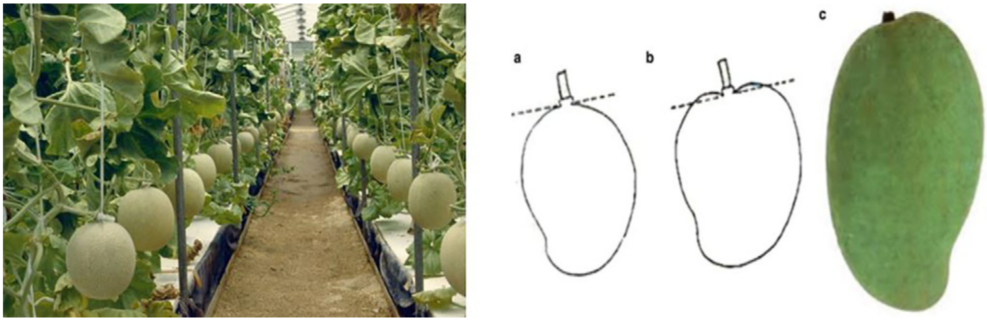

FIG. 5.9 Melons ready for harvest (left) and Mango maturity stages (a) immature stage; (b) mature stage; (c) ideal maturity (right) (Ahmad and Siddique, 2015).

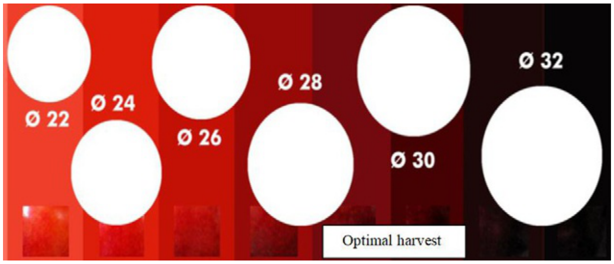

FIG. 5.10 Size and color relation in sweet cherries (Güneyli and Onursal, 2014).

layer that becomes weakened and broken down by the conversion of pectin to pectic acid. Consequently the fruit can easily be picked from tree by hand. The abscission layer can be formed between fruit and fruit stalk or fruit stalk and branch. Once it is formed the fruit can easily be removed. Harvesting should be made with the attached peduncle. Otherwise, fruit having no peduncle at harvest results in a low marketing quality (Fig. 5.11). In most cases, fruit harvested before development of the abscission zone will not have well-developed sugar, volatile, or flavor attributes. The formation of the abscission layer decreases in hot climates while it rises in cold climates. In some cases, premature abscission occurs as a result of insect damage, disease, wounding, chilling injury, drought, and other unfavorable conditions. The use of some growth regulators before harvest is useful for the forming of abscission layer. The use of naphthalene acetic acid (NAA), 1-Methylcyclopropene (1-MCP, Harvista™) and aminoethoxyvinylglycine (AVG, ReTain®) delay the formation of abscission layer.

5.2.3.14 Days From Full Bloom to Harvest

In some fruits the time between fruit set to maturity, expressed in days, can be used to determine harvesting time. This index is a good harvest parameter for apples, pears, quinces, plums, nectarines, peaches, and cherries. For example, in Golden Delicious apples, maturity takes 150–155 days after full bloom (Table 5.3). Each cultivar has its own pattern of maturity, and therefore the length and timing of the harvest window may differ from year to year and from region to region.

FIG. 5.11 Apples harvested without peduncle (left) and with peduncle (right).

5.2.3.15 Hull Splitting

One of the most import maturity indices for nut fruits (e.g., almonds, walnuts and pistachios) is hull splitting (Fig. 5.12). For example, for almonds the hull split usually starts in the upper and outer sections of a tree, where it gets most of the sunshine during the day.

5.2.3.16 Dry Matter and Oil Content

Dry matter and oil content can be used to determine the maturity of some fruits such as avocados. For further ripening after harvest, avocado fruit must contain certain amount of dry matter at harvest. The average dry weight at harvest in California and Mexico is 19.4% for Bacon, 19.1% for Fuerte, 19.8% for Hass, 18.9% for Pinkerton, and 18.4% for Zutano cultivars. In avocado fruit, the increase in oil content during ripening is used as a maturity index in some regions. For example; a minimum of 8% oil is used as a maturity index for Hass avocado cultivar.

5.2.3.17 Respiration Rate and Ethylene Production

The most reliable information on the physiological age of climacteric fruits and vegetables during maturation is respiration rate. In fruits and vegetables, after cell division, cell proliferation and tissue differentiation continue for a certain period of time. During these growth and development periods the rate of respiration steadily decreases and reaches a minimal point called “climacteric minimum.” This period is the optimal harvesting time for some fruits and vegetables intended for long-term storage periods. With the initiation of fruit ripening the respiration rate of fruits and vegetables rises from the "climacteric minimum" to the "climacteric maximum," indicating the ripening of the fruit. Palatability of the fruit coincides in many cases with the climacteric maximum. When the fruit reaches a climacteric maximum the respiratory rate drops steadily as the fruit enters the senescence phase (postclimacteric stage). In some horticultural crops the climacteric minimum and optimal harvesting time overlap depending on the ecology.

TABLE 5.3 Days After Full Bloom to Harvest Time in Some Temperate Zone Climate Fruits (Güneyli and Onursal, 2014)

Species	Cultivars	Days Full Bloom to Harvest	Species	Cultivars	Days Full Bloom to Harvest
	Starking Delicious	155–160		Formasa	120–130
	Golden Delicious	150–155		Santarosa	120–130
Apple	Amasya	160–170		Black Beauty	125–135
	Granny Smith	180–190	*Plum*	Angeleno	175–185
	Red Chief	140–150		Papaz	80–90
	Jersey Mac	100–110		Stanley	125–135
	Bing Spur	40–45		Grand Prise	120–130
	Stella	55–60		Gaint	145–155
	Van	55–65		Spring Time	90–100
Sweet Cherry	Jubile	55–65		Spring Lady	100–110
	0900 Ziraat	60–70		July Elberta	125–135
	Morten Late	65–75	*Peach*	Elegant Lady	130–140
	Akça	75–85		Alyanak Hale	165–175
	Santa Maria	115–125		Monreo	170–180
	Williams	135–145		Early Sun Grad	90–100
Pear	Abba Fetel	140–150		Spring Red	95–105
	Ankara	150–160	*Nectarine*	Sun Red	100–110
	Deveci	150–160		June Berta	105–115
	Kieffer	140–150			

In climacteric fruits, ethylene production rises close to maturation. Ethylene is a naturally synthesized plant hormone that plays a key role in initiating fruit ripening, therefore internal or external ethylene concentrations can be used to determine maturity and ripening stages. However, this parameter may not always be reliable because it can be significantly influenced by factors such as the production region, cultivar, and the growing season. Due to this constraint, we should combine other maturity indices when predicting harvest maturity. Internal ethylene concentrations are generally below 0.15 ppm at harvest for apples. As ripening initiates the production of ethylene increases dramatically up to 100 times in just 2 days. The onset of ethylene production for Cox's Orange Pippin and Braeburn is the a marker for the completion of the harvest for these cultivars. The measurements of respiration rate and ethylene production require special devices, such as gas chromatography (GC) or other gas analyzers.

Fruits and vegetables are classified according to their respiratory behavior, namely climacteric and nonclimacteric fruits. Climacteric fruits show a sudden increase in carbon dioxide (CO_2) and ethylene (C_2H_4) production coincident with maturation and ripening. Nonclimacteric fruits show almost no increase in CO_2 and C_2H_4 production during ripening. The list of climacteric and nonclimacteric fruits are given below.

FIG. 5.12 Splitting of hull in almond and almond harvest by using a long stick.

Climacteric fruits: Apple, mango, papaya, kiwifruit, tomato, cherimoya, banana, pear, apricot, peach, plum, avocado, plantain, fig, guava, jackfruit, muskmelon, nectarine, passion fruit, persimmon, quince, blueberry, cantaloupe, feijoa, sapodilla, breadfruit, broccoli, durian, mangosteen, and sapote.

Nonclimacteric fruits: Orange, grapefruit, lemon, lime, cranberry, raspberry, strawberry, cherry, blackberry, grape, pineapple, lychee, melon, loquat, pomegranate, cucumber, tamarillo, carambola, cashew-apple, eggplant, jujube, longan, okra, peas, pepper, summer squash, watermelon, prickly pear, rambutan, snap bean, cacao, date, olive, and pumpkin.

5.2.3.18 Flavor and Aroma

Two main factors determining a fruit's characteristic flavor are the sugar/acid ratio and the production of aroma compounds. Aroma volatiles are important attributes of flavor in almost all fruits and vegetables. The earlier fruits are harvested, the poorer their ability to produce aroma volatiles. These volatile compounds can include a mixture of chemical classes such as acids, aldehydes, alcohols, esters, and terpenoids.

The increase in aroma production is related to ripening. In apples a rapid increase in volatile production, namely butyl acetate, is released shortly after harvest in fruits picked at the climacteric rise. Fruit that has already reached climacteric maximum at harvest produces maximal volatiles just after harvest and shows a decline in volatile emanation. The production of aroma compounds can be used in determining the time of harvest in some crops such as apples, pears, strawberries, bananas, melons, but it is difficult in practice because it requires analytical methods commonly not easily available for growers nor easily used.

The overall harvest maturity determination of different fruits and vegetables is presented in Table 5.4.

TABLE 5.4 Summary of Maturity Indices for Different Horticultural Crops

Species-Maturity Indices	Days After Anthesis	Days After Planting	Skin Color	Flesh (Seed/Aril) Color	Flesh Firmness	Juice Content	Soluble Solids Content (SSC)	Titratable Acidity (TA)	Ripening Index (TSS/TA Ratio)
Apple	+		+		+		+		
Pear	+		+		+		+		
Quince	+						+		
Peach			+	+	+		+		+
Apricot			+	+	+		+		+
Plum			+	+	+		+	+	+
Sweet/Sour Cherry			+	+	+		+	+	+
Mandarin/ Orange/ Grapefruit						+	+	+	+
Lemon						+			
Grape			+		+		+	+	+
Fig			+	+			+		
Pomegranate			+	+			+	+	+
Banana	+								
Olive			+						
Kiwi							+		
Avocado									
Mango				+					
Papaya			+	+			+		
Guava			+						
Tomato			+	+			+	+	+
Pepper			+						
Melon				+			+	+	
Watermelon				+			+		
Radish		+							
Lettuce									
Broccoli									
Carrot									
Hazelnut									
Walnut									
Almond									

TABLE 5.4—cont'd

Species-Maturity Indices	Starch-Iodine Test	Oil Content	Internal Ethylene	Respiration Climacteric	Abscission Layer	Hull Splitting	Size and Shape	Aroma Production	Firm Head/Compactness
Apple	+		+	+	+		+	+	
Pear	+		+	+	+		+		
Quince			+	+			+		
Peach			+	+			+		
Apricot			+	+			+		
Plum				+			+		
Sweet/Sour Cherry					+		+		
Mandarin/Orange/Grapefruit							+		
Lemon							+		
Grape							+		
Fig							+		
Pomegranate							+		
Banana	+			+			+		
Olive		+					+		
Kiwi				+			+		
Avocado		+		+			+		
Mango							+		
Papaya									
Guava									
Tomato				+			+		
Pepper							+		
Melon				+	+		+	+	
Watermelon							+		
Radish							+		
Lettuce									+
Broccoli									+
Carrot							+		
Hazelnut					+		+		
Walnut					+	+	+		
Almond					+	+	+		

5.2.3.19 Nondestructive Methods

DA (DELTA ABSORBANCE) METER

The DA meter is a portable Vis/NIR instrument that uses absorbance between 670 and 720 nm to nondestructively determine the chlorophyll content of fruit skin. DA meter provides a reading index of absorbance difference (I_{AD}). The I_{AD} value correlates with the chlorophyll content in the mesocarp (flesh) of the fruit and can be used as a maturity indicator of apples or pears. DA meter provides readings in the range of 0–3.0 for apples. Higher values represent greener skin color, while lower values represent reddish skin color. For example: I_{AD} values of 0.59–0.36 proposed as "start" and "finish" dates for long term air store of Honeycrisp apples. The use of a DA meter and I_{AD} value to determine the optimal harvesting time may be applicable to all apple cultivars, but cultivar-based specific studies should be conducted for each cultivar and growing region.

5.3 HARVESTING

It is important to harvest fruits and vegetables at the optimal stage of maturity in order to maintain their postharvest quality as well as consumer satisfaction.

Three different methods for harvesting are commonly used:

- Harvesting individual fruits and vegetables manually by pulling or twisting the fruit pedicel.
- Harvesting individual fruits or fruit bunch/vegetables or vegetable bunch with the help of clippers, secateurs, or scissors.
- Harvesting using specially designed mechanical harvesters.

The following points should be considered during harvesting:

- Harvest bags and other harvest equipment must be cleaned before harvest to prevent development of fungal pathogens.
- Gentle picking and harvesting will maintain maximum fruit quality and reduce losses.
- Wearing gloves, trimming finger nails, and removing jewelry can help reduce mechanical damages.
- Crops should be harvested during the cooler hours of the day. Harvesting should not be done during or right after rain to reduce cracking in some crops such as cherry and pomegranates.
- Harvested crops should be kept in the shade until transported to packing houses or markets.
- Picking containers should be emptied with care.
- Precooling is essential to lower the product's temperature and respiration right after harvest.
- Transportation to packing houses or warehouses and unloading should be well coordinated to minimize each loaded vehicle's waiting time in direct sunlight.

Harvesting can be done by two methods:

1. *Selective or multiple picking method*: In this type of harvesting, only fruit that reaches the harvest maturity can be picked, while unripe or undeveloped fruit is left on the plant or tree

FIG. 5.13 Selective harvest in cucumber (left) and fig fruits (right) (fruits in different development stages).

for future harvesting (Fig. 5.13). Pomegranates, figs, strawberries, cucumbers, tomatoes, zucchini, peppers, eggplants, beans, artichokes, melons, and watermelons are harvested more than once. The harvest in these crops can last for several weeks. Greenhouse tomatoes, peppers, and eggplants are harvested for almost a whole year under appropriate maintenance conditions.

2. *Strip picking method*: The entire crop is picked or harvested at once. For example, apple, pear, quince, cherry, apricot, peach, plum, almond, walnut, processing tomatoes, citrus fruits, and sour cherries are all harvested at one time or in a short duration within 1–2 weeks. As there are variations in maturity levels of fruits on trees or plants, this method of harvesting is not recommended for many crops.

5.3.1 Care at Harvest

Horticultural crops are very perishable and continue to respire even after harvest; therefore maximum care is needed during harvest to reduce damage and losses. The proper harvest management of fruits and vegetables is not the same for all commodities. Some of the crops such as apples, pears, quinces, medlars, pumpkins, and melons do not need as much maximum care as in the case of apricots, figs, cherries, grapes, and berries.

Manual harvesting is done by hand or by using harvest clippers. Some fruits such as apples, pears, peaches, apricots, and quinces are harvested by hand because an abscission layer is formed in these crops. However, in some other fruits such as citrus, pomegranates, and grapes, the abscission layer is not developed and therefore they are harvested with clippers. Careful and correct harvest techniques are essential to ensuring the integrity of the harvested produce. Mechanical injuries and wounding during harvest may offer a penetration point for pathogens that cause decay.

Harvesting should start very early in the morning during the cooler hours of the day. Scratches, bruises, injuries, and mechanical damage on the surface of the fruit increase injuries and decays resulting in decreased marketing and postharvest quality (Fig. 5.14). For these reasons the nails of the pickers should not be long, gloves should be worn, and crops

FIG. 5.14 Harvest damage in pepper (left), pomegranate (middle) and mandarin (right) fruits.

consumed for the fresh market should be harvested manually. In addition, harvest bags, boxes, crates, clippers, and other equipment must be cleaned before harvest.

5.3.2 Harvesting Equipment

Cleaned harvesting equipment and containers must be used in order to prevent decay development, reduce damage, and prolong the postharvest life of the fruits and vegetables. Harvesting equipment can be cleaned by using sodium hypochlorite solution (chlorine bleach) or other appropriate materials before harvest.

5.3.2.1 Harvesting Bags and Containers

Harvesting containers may include a wide range of sizes, types, and materials, depending on the produce and country. Wooden baskets and buckets, metal and plastic bins, plastic and wooden bulk boxes, and linen and plastic bags of canvas and nylon mash are used for harvesting (Fig. 5.15). Special care should be taken in choosing the containers to minimize harvest damage. Picking baskets and harvesting containers can be made by sewing bags with openings on both ends and fitting fabric over the open bottom of ready-made baskets. Metallic buckets used for harvesting should be cushioned to reduce damage. Plastic crates are durable, reusable, and easy to clean. A number of different crate designs are available and used in different countries. The containers must be cleaned before harvesting is initiated.

FIG. 5.15 Different picking containers for harvest (Candir and Ozdemir, 2017).

FIG. 5.16 Using movable ladders for apple (left) and cherry (middle) and two-legged ladder (right) for cherry harvest. *(Courtesy of Ornek Tarim, Karaman, Turkey)*

5.3.2.2 Clippers and Knives

Some fruits such as citrus, grapes, and pomegranates need to be picked by using specific clippers or scissors. These tools should be kept well sharpened and cleaned before harvest. In some cases, harvesting should be made by cutting twice for trimming in some fruits. The first cut is made from peduncles, green buttons, or spurs to remove fruits from trees, and the second cut should be made to trim excess peduncles to prevent damaging other fruits during harvesting or transport.

5.3.2.3 Ladders

A ladder is important to reach the fruit (e.g., avocados, oranges, grapefruits, apples, pears, peaches, and plums) on the upper parts of trees and to prevent damage to the tree and fruit branches. Ladders are either placed alongside trees or rested against the canopy of larger trees. Different types of ladders such as movable, single-sided, two-legged and three-legged ladders, generally made from aluminum, metal, or wood, are used during harvest (Fig. 5.16). A ladder with three legs is very convenient and more stable than the other types of ladders.

5.4 HARVESTING TYPES

Harvesting of horticultural commodities is carried out by using three methods of harvesting systems:

- Manual
- Semimechanical
- Mechanical

Manual harvesting is highly laborious and inefficient in terms of both economy and time; therefore efforts have been devoted to developing semimechanical and mechanical harvesters to decrease extensive labor costs. This is a problem particularly in developed countries, but it does not create a problem in developing countries where there is a huge, cheap labor force. Semimechanical and mechanical harvesting systems are a partial solution, as they remove fruits from trees to reduce harvesting cost by 35%–45% of total production cost. For fresh consumption the harvesting of fruit and vegetables is done by hand to minimize injuries and to maintain postharvest quality for longer durations. Thus the harvesters or pickers should decide correctly whether fruit is mature enough to pick.

5.4.1 Manual (Hand) Harvesting

Most of the fruits and vegetables intended for fresh consumption are picked manually by hand (Fig. 5.17). Manual harvesting is a selective method, and the crops can be harvested several times. In this method, pickers or harvesters must determine the maturity level of the crop as precisely as possible. This is particularly important for the crops that have a long maturation period and need to be harvested several times during the harvest season. This method reduces the mechanical damage of the harvested produce. In some cases, hand harvesting requires the use of different equipment such as secateurs, knives, clippers, and digging tools for tuberous vegetables.

There are advantages and disadvantages of manual harvesting.

Advantages of manual harvesting

- Fruits and vegetables can be selected more precisely at the optimal maturity stage compared to mechanical harvesters.
- Fruit and vegetables are carefully handled and therefore damage is minimized.
- Manual harvesting requires minimum capital investment, but it can be expensive in the long-term.

Disadvantages of manual harvesting

- Labor requirements can be a big, and expensive problem, particularly in developed countries.
- Harvesting can take quite a long time.
- Possible labor strikes during the harvest period can be a problem for growers.
- New workers may require intensive training.

FIG. 5.17 Pepper (left), strawberry (middle), and fig (right) are harvested by hand.

5.4.2 Semimechanical Harvesting

Semimechanical harvesting systems are used to reduce the disadvantages of both manual and mechanical harvesting systems. For example, belt conveyors are used with certain vegetables, such as lettuce and melons, to move them toward a central loading or infield handling station. Scoops with rods protruding from the end are used by workers to comb through some berries. Platforms or moveable worker positioners have been used in place of ladders in crops such as apples, pears, citrus, dates, papayas, and bananas. Furthermore, hand-held, vibrating shakers are used to detach olives, nuts and some berries from the plants. Semimechanical harvest systems are aimed to minimize harvest costs while increasing the harvest efficiency. Blueberries harvested by traditional over-the-row harvesters may be bruised and become soft within a short period of time. For this reason, semimechanical harvesting systems have been tested for blueberries (Fig. 5.18).

5.4.3 Mechanical Harvesting

Mechanical harvesting systems are designed to achieve the mass removal of the commodity during the harvesting season at once. This method has been practiced by shaking the trunks, limbs, and canopies of plants. In some cases, chemicals have been used to loosen the mature fruits by developing an abscission layer to increase harvest efficiency. It is necessary to choose appropriate mechanical harvesters to minimize harvest damage. In most fruits and vegetables, mechanical harvesters cannot maintain the quality and size selection compared to hand harvesting. After harvest a selection process should be carried out to maintain the quality.

In general, mechanical harvesting currently used for freshly consumed fruits and vegetables is done for some root, tuber, or rhizome and shell crops, including nuts. Tuberous and root vegetables such as radishes, potatoes, garlic, and carrots are commonly harvested only once. Fruits

FIG. 5.18 Semimechanical harvester for blueberry fruit. *(Courtesy of Fumiomi Takeda)*

and vegetables grown for processing (e.g., tomatoes, wine grapes, beans, peas, sour cherries, apricots, prunes, peaches, and some leafy vegetables) are sometimes harvested by mechanical harvesters. As harvest damage does not significantly affect the quality of these products compared to those consumed fresh, these species should be bred accordingly or produced with a proper technique in order to obtain more efficient harvester use. The main advantage of mechanical harvesting is that these machines can harvest fruit and vegetables within short periods of time. For example, nut harvesters can remove most of the nuts from the tree within a few minutes. Mechanical harvesting also reduces management problems associated with workers, where problems associated with hiring and managing workers are reduced. For example, under US conditions, at one ha of sweet cherries the mechanical harvest cost equaled $0.72 per box, whereas the hand-harvest cost equaled $1.79 per box (Smith, 2009).

Similar to manual harvesting, there are advantages and disadvantages of mechanical harvesting.

Advantages of mechanical harvesting:

- Reduce harvest cost
- Accelerate harvesting
- Use labor force effectively

Disadvantages of mechanical harvesting:

- No precise judgment for optimal maturity
- No selective harvesting
- Not appropriate for crops requiring multiple harvests
- May cause excessive damage to fruit and tree/plants
- Can be quite expensive for small scale orchards/fields

5.4.3.1 Mechanical Harvesters

There are different types of mechanical harvesting methods, such as limb shaking, canopy shaking, trunk shaking, air blasting, and robotic harvesting.

LIMB SHAKER

Limb shakers are used to harvest the fruits for processing. For example, citrus fruits, apricots, prunes, peaches and sour cherries can be harvested by using limb shakers. Shakers can be controlled remotely from the operator's handle on the shaker. These limb shakers are effective in removing a high percentage of fruit by imparting long strokes to limbs at a low frequency. In this method, bark and limb damages may occur on the tree, and even immature fruits can be removed. The efficiency of this harvesting system depends on the cultivars and operating conditions at the orchard. The use of abscission chemicals have been promoted to increase the harvest efficiency.

CANOPY SHAKER

In this system, fruits are harvested by the vibrating mechanism causing the tines to impact fruit directly or by impacting fruit-bearing branches. The canopy shaker can be used to clamp secondary limbs to shake vertically to pick the fruit. Two types of continuous canopy shakers are used especially for citrus fruit: one was a self-propelled unit and the other was a tractordrawn unit. The shaking frequency and stroke are important factors for the performance of this type of harvester. The most common mechanical harvesting system used for oranges in Florida is a canopy shaker composed of a vertical axis with 12 sets of free-floating tines 2 m long that radiate out from the vertical axis. The percent of the total crop removed at any given time during the harvest period is a function of the depth of placement of the shaker within the canopy, frequency of shaking each set of tines, tractor speed, and fruit detachment force.

Some fruits such as citrus fruits are difficult to harvest mechanically because they remain firmly attached to the tree when they are mature; therefore mechanical harvesting systems can cause significant limb and tree damages.

TRUNK SHAKER

Trunk shakers are used to remove fruit, mainly deciduous fruits, olives, nuts, and citrus fruits. Generally a tractor-mounted trunk shaker (Fig. 5.19) is used on cultivars of different fruits in comparison to a hand-held shaker. Overall the tractor-mounted shaker is more effective, with about a 72% detachment than the hand-held shaker with a 57% detachment. However, in this system, defoliation risk can be a problem at a high-shaking frequency. Furthermore, trunk shakers cause certain problems by damaging trees resulting in more susceptibility for fungal attacks. The removal rate of trunk shakers varies from 67% on large trees

FIG. 5.19 Tractor-mounted trunk shaker for apples. *Courtesy Feucht Obsttechnik GmbH Company.*

to 98% on small trees. For example the percentage of fruit detached by the trunk shaker ranges between 70% and 85% on mandarins and oranges in Spain (Moreno et al., 2015).

AIR BLAST

A force-generated air blast may be used to remove the fruit from the tree. In this system, oscillating air blast machines are used, and the fruit detachment rate is maximized by the oscillation rate. The performance of an air blast harvester is dependent on various factors, such as the tree structure, size, weight of the fruit, and fruit load of trees.

ROBOTIC HARVESTER

Despite the high degree of mechanization and automation in agriculture, very few robotic harvesters have evolved beyond the research stage, and none are widely used in open fields. The limited success of robotic harvesters is mainly due to the complexity of the terrain, environment, and mission, which results in low fruit-picking success ratios or operations that are too slow to be economically relevant. Research on robotic harvesters is ongoing.

5.4.4 Use of Abscission Chemicals

Abscission chemicals can be used to loosen the mature fruit and accelerate the fruit removal rate. Moreover, abscission agents may enhance the development of the absiccion layer, resulting in lower mechanical forces to be applied during harvest and minimizing fruit damage. Some abscission layer-forming chemicals or agents used to help with the detachment of fruit from the tree include Ethephon, 1-aminocyclopropane-1-carboxylic acid (ACC), and 5-chloro-3-methyl-4-nitro-1H-pyrazole (CMNP). For example, the use of abscission layer-forming chemicals in oranges increase the percentage of detachment achieved by limb shakers by up to 20%–35% and removal rates of 81%–91% in Valencia and 93%–100% in Hamlin oranges (Moreno et al., 2015).

Processing tomatoes can be harvested by using fully mechanized harvesters at present. A tomato harvester works as follows (Fig. 5.20):

FIG. 5.20 Mechanical harvest in tomato (left) and rucola (right).

1. Cut the plants stalks at ground level from the soil.
2. Separate the fruit from the stalk by shaking it with the harvester.
3. Sort out the loose fruit from the rest of the plant with a conveyor system.
4. Load the fruit into the bins trailing behind the harvester.

Other fruits and vegetables such as rucola (Fig. 5.20), parsley, and lettuce can be harvested using different types of harvesters as well.

5.5 CONCLUSIONS

Fruit maturity at harvest greatly affects the postharvest quality of all fruits and vegetables along the postharvest value chain. Accurate, efficient, and effective maturity indices must be used in order to supply high-quality fruits and vegetables for consumers and processors. A single maturity index cannot be used to predominantly determine the maturity of fruits. The combination of several indices is superior to a single test, as each index provides information about the fruit's maturity stage, to minimize fruit-to-fruit, seasonal, and location-related variability.

Maturity indices also depend on the market destination, shipping time, and growing regions. Different producer countries may apply certain maturity standards. The distance to the market and, consequently, transportation time, are among the more important parameters to be considered when taking harvest decisions.

In recent years, there have been attempts to use nondestructive methods for determining harvesting time and maturity. These techniques will help to determine the optimum harvest maturity and consumer satisfaction.

During the last decade the use of mechanical and/or semimechanical harvesters have increased for harvesting different fruits and vegetables, mainly to decrease labor costs. However, planting systems used in old orchards are not suitable for the new harvesting systems. Furthermore the uniform ripening of fruit and vegetables is still a major constraint for the success of these new harvesting systems. However, in some parts of the world, horticulture is still highly labor intensive. Using mechanical harvesters have had a major impact on the demand and supply for farm labor; the profitability and the change in the rural landscape, including rural communities. In the future, robotic harvesters may be used for fruit harvesting.

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Further Reading

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