CHAPTER 8

Transpiration

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8.1 INTRODUCTION

Water is a compound directly associated with life processes. It is the essential medium where biochemical reactions occur and a major constituent in plant cells. Water is the most abundant component in fruit and vegetables. Water content in fruits and vegetables can range from about 10% in dried seeds to about 95% in fresh vegetables and fruit, such as watermelon.

Together with temperature, transpiration is one of the most important factors determining deterioration and shelf life in fruits and vegetables. A strong understanding of the environmental and biological factors that determine produce transpiration and the ways transpiration affects the quality of fruits and vegetables is essential to developing effective approaches to manage produce transpiration and prolong the shelf life of fruits and vegetables.

8.2 PHYSICAL PROPERTIES OF WATER

Water has distinctive physical properties that make living processes possible. Those properties derive from the structure of water and from the ability of hydrogen and hydroxyl ions to dissociate in solution.

Some important water properties include the following:

- Water is the substance with the highest specific heat, except liquid ammonia; this property tends to stabilize temperatures.
- Water is in liquid state at normal temperatures.
- Water is a strong solvent, thus it serves as a means for transport of nutrients and provides a substrate for cell biochemical reactions.
- Water has high heat of vaporization (540 cal/g at 100°C) and high heat of fusion (80 cal/g). These properties allow water evaporation to have a cooling effect and water condensation to have a warming effect.

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- Water has high heat conductivity.
- Water is transparent to visible radiation.
- Water is an effective solvent for nonelectrolytes because the positive (H^+) and negative (OH^-) charges of water molecules attract ions. Water is a dipole because of the asymmetry of the angles of the two covalent O—H bonds. This polarity allows for the formation of H bonds between water molecules.
- Water has a higher surface tension than the majority of liquids.
- Water has a high density and its maximal density is at 4°C.
- Water expands at freezing. A given volume of water at the frozen state is 9% greater than the same amount of water at the liquid state.
- Water has low ionization. Only one water molecule is ionized (dissociated) out of 55.5×10^7.
- Water may be bound or adsorbed to surfaces of cellulose, starch, proteins, etc.

8.3 PHYSICS OF WATER LOSS

Water *evaporation* is a phase transition from the liquid phase to vapor that occurs at temperatures below the boiling temperature. It occurs on the surface of the liquid (Britannica, 2018). Water evaporation occurs when the partial pressure of water vapor is less than the equilibrium water vapor pressure.

Transpiration (from Latin *trāns* through + *spīrāre* breath) is a type of water evaporation or water loss from plant parts (Kramer and Boyer, 1995). Transpiration involves the evaporation of water from cell surfaces into intercellular spaces and the diffusion of water molecules out of the plant tissue or organ into the surrounding air.

Transpiration in plants and harvested fruits and vegetables works following the physical laws that determine water evaporation from moist surfaces. Transpiration is proportional to the water vapor pressure gradient between the surface of the commodity and the surrounding air, and inversely proportional to the resistance to transpiration (e.g., cuticular resistance).

The *vapor pressure of water* is the equilibrium pressure of water vapor above liquid (or solid) water. It is the pressure of the water vapor molecules resulting from evaporation. The vapor pressure of water increases with temperature, that is, more water molecules are evaporated at high compared to low temperatures (Table 8.1). The difference between the vapor pressure of the air and the vapor pressure of the evaporating surface is what determines the rate of transpiration from produce. This difference in vapor pressure is called the *vapor pressure difference* or *vapor pressure deficit* (VPD). *Relative humidity* (RH) is the water content of the air expressed as a percentage relative to the vapor pressure of the same air, saturated, and at the same temperature. Table 8.2 provides an example on how to calculate VPD.

Table 8.1 Saturation Vapor Pressure Over Water[a]

Temperature (°C)	Vapor Pressure (kPa)	Temperature (°C)	Vapor Pressure (kPa)
1	0.657	26	3.361
2	0.705	27	3.565
3	0.758	28	3.78
4	0.813	29	4.005
5	0.872	30	4.243
6	0.935	31	4.493
7	1.001	32	4.755
8	1.072	33	5.031
9	1.147	34	5.32
10	1.227	35	5.624
11	1.312	36	5.942
12	1.402	37	6.276
13	1.497	38	6.626
14	1.598	39	6.993
15	1.704	40	7.378
16	1.817	41	7.78
17	1.937	42	8.202
18	2.063	43	8.642
19	2.196	44	9.103
20	2.337	45	9.585
21	2.486	46	10.089
22	2.643	47	10.616
23	2.809	48	11.166
24	2.983	49	11.74
25	3.167	50	12.34

[a] *Fruits and vegetables have a high water content (90% or more). Thus, for calculating vapor pressure differences between the produce and its surrounding air, the produce is considered to be "at water saturation."*

Source: Data from Pearcy, R.W., Ehleringer, J., Mooney, H.A., Rundel, P.W., 1991. Plant Physiological Ecology. Field Methods and Instrumentation. Chapman and Hall, London.

8.4 TRANSPIRATION OF FRUITS AND VEGETABLES ATTACHED TO THE PLANT

In plants, transpiration is beneficial because it cools the leaves and produces the water potential gradient that allows for water and nutrient uptake from the soil (Kramer and Boyer, 1995). It is an "unavoidable evil" because, in order for leaves to receive CO_2 from the air, leaves have to "pay the price" of losing water.

When fruits and vegetables are still attached to the plant, they maintain a relative balance between the amount of water they lose through transpiration and the water they receive from the soil. Fruits' and vegetables' water status is not constant, but rather changes during the day. During the night and early

Table 8.2 Example on How to Determine Vapor Pressure Difference Between a Commodity and the Surrounding Air

Storage or ambient temperature: mean = 20°C
Storage relative humidity (RH) = 70%
Vapor pressure difference (VPD)
To calculate VPD, we need to know the ambient (storage conditions) temperature and RH, and the temperature of the commodity. After a few hours under storage, we can assume that air temperature and fruit temperature are the same. We assume that the RH of the commodity is 100%
With the temperature information, we find the vapor pressure of the air at saturation (Table 8.1)
Vapor pressure of air at 20°C at saturation (100% RH) = 2.337 kPa
Partial vapor pressure of air at 20°C at 70% RH = 2.337 × 0.70 = 1.636 kPa
Partial vapor pressure of commodity at 20°C and 100% RH = 2.337 kPa
Vapor pressure difference between commodity and air = 2.337 kPa − 1.636 kPa = 0.701 kPa

morning, when the plant has low water loss through transpiration, the produce is well hydrated (i.e., it has a high water status). As the plants show an increasing rate of water loss, as air temperature and evapotranspiration increase, fruits and vegetables show decreased water status because the produce loses more water than the amount of water it receives from the roots. Fruits may show diurnal fluctuations in size in addition to long-term irreversible enlargement. Diurnal fluctuations are related to plant water status (Johnson et al., 1992; Thompson et al., 1999). In tomato fruit, the maximum relative growth rate occurs in the morning and the minimum relative growth rate at midday (Díaz-Pérez and Shackel, 1991). Vegetables (e.g., leafy vegetables) also show changes in plant water status during the day because of imbalances in the amount of water taken up from the soil and the amount of water lost by transpiration. These physiological responses of crops to the environment explain the common practice of harvesting the produce in the morning, when fruits and vegetables are highly hydrated. Another example is melon fruits which, when harvested in the morning, are heavier than those harvested at midday; melon fruit harvested in the morning, however, tend to have reduced soluble solid content compared to melons harvested at midday.

8.5 TRANSPIRATION OF FRUITS AND VEGETABLES AFTER HARVEST

The commercial postharvest life of fruits and vegetables may be determined by transpiration, decay, physiological disorders or processes (chilling injury, overmaturity, decay, spouting, rooting, undesirable color changes, off-flavors, and elongation), mechanical injury, etc. (Ben-Yehoshua and Weichmann, 1987). Transpiration is one of the most important factors determining deterioration in fruits and vegetables (Kader, 1992), as in leafy vegetables (spinach, lettuce, and chard), cabbage, mushrooms, and green onion.

In harvested fruits and vegetables, transpiration is undesirable because water loss cannot be compensated by more water uptake from the soil since the produce are not attached to the plant any more. The amount of water in a commodity at harvest time is the maximum of water the commodity will have. Thus, any water loss from the commodity after harvest will result in produce dehydration.

The water loss from fruits and vegetables induces water stress in their tissues. This water stress may enhance or accelerate senescence in commodities, probably because of an increased rate of cellular membrane disintegration and leakage of solutes (Ben-Yehoshua et al., 1983). Excessive water loss results in produce softening and shriveling, loss of peel gloss and calyx browning due to dehydration in eggplant (Risse and Miller, 1983).

Symptoms of produce water loss. Postharvest transpiration causes a loss in cell turgor that is manifested by produce softening (e.g., bell pepper, eggplant, etc.), shriveling (e.g., citrus, cucumber, lettuce, spinach, mushroom, potato, etc.), and loss of shine (e.g., eggplant, mango, cucumber, etc.), epidermis color change (e.g., whitening of carrots), among other factors detrimental to produce quality (Fig. 8.1).

Allowable weight loss in commodities. Commodities vary in their tolerance to water loss. The *allowable weight loss* before the commodity becomes unmarketable ranges from about 3% to 10% of the weight of the commodity immediately after harvest (Table 8.3). An allowable weight loss of 5% is typical for many commodities. As a rule, shriveling is visible at about half the total figure of the allowable weight loss. This means that half of the commercially allowable weight loss is not visible. Above the maximum allowable weight

FIGURE 8.1

Bell pepper fruit immediately after harvest (left), 3 days after harvest (center), and 7 days after harvest (right). Fruit kept at 20°C and 70% RH.

Table 8.3 Transpiration (Water Loss) Rates From Various Commodities After Harvest

Commodity	Water Loss Rate[a] (% of Initial wt./day/kPa)	Temperature of Measurement (°C)	Maximum Allowable Water Loss (% Original Commodity Weight)
Asparagus	36[a]	10	8[a]
Beans, broad	21[a]	15	6[a]
Beans, runner	18[a]	15	5[a]
Beetroot storing	16[a]	10	7[a]
Beetroot, bunching w/ leaves	16[a]	15	5[a]
Bell pepper	0.6[d]	20	7[a]
Blackberries, Bedford	5[a]	10	6[a]
Broccoli, sprouting			4[a]
Brussels sprouts	28[a]	15	8[a]
Cabbage Primo	10[a]	10	7[a]
Cabbage Decema	1[a]	10	10[a]
Carrots, storing	19[a]	10	8[a]
Carrots, bunches with leaves	28[a]	15	4[a]
Cauliflower, April Glory	19[a]	15	7[a]
Celery, white	18[a]	15	10[a]
Cucumber	4[a]	15	5[a]
Eggplant, Classic	0.6[b]	20	
Eggplant, Japanese	5.7[b]	20	
Leeks (“Musselburgh”)	9[a]	15	7[a]
Lettuce, Unrivalled	75[a]	15	5[a]
Onion, Bedfordshire Champ	0.2[a]	15	10[a]
Parsnip, Hollow Crown	24[a]	15	7[a]
Peas in pod, early	13[a]	15	
Peppers, green	6[a]	10	

(*Continued*)

Table 8.3 (Continued)

Commodity	Water Loss Rate[a] (% of Initial wt./day/kPa)	Temperature of Measurement (°C)	Maximum Allowable Water Loss (% Original Commodity Weight)
Potato, main crop, King	0.5[a]	15	7[a]
Potato, new (immature)	5[a]	15	7[a]
Raspberries, Malling Jewel	25[a]	10	6[a]
Rhubarb, forced	23[a]	10	3[a]
Sapote mamey	1.4[c]	20	
Spinach, Prickly True	110	15	3[a]
Sprouting broccoli	75[a]	15	4[a]
Strawberries, Cambridge	7[a]	15	6[a]
Sweetcorn	14[a]	15	7[a]
Tomato, Eurocross	1[a]	10	7[a]
Turnip, bunching with leaves	11[a]	10	5[a]
Watercress	350[a]	15	7[a]

Transpiration is expressed as commodity weight loss relative to the initial weight of the commodity.

[a] *After Robinson, J.E., K.M. Browne, Burton, W.G., 1975. Storage characteristics of some vegetables and soft fruits. Ann. Appl. Biol. 81, 399–408. Data were transformed from "% of initial wt./day/mbar" into "% of initial wt./day/kPa".*

[b] *Díaz-Pérez, J.C. 1998a. Packaging of 'Classic' and 'Japanese' aubergines (*Solanum melongena*) with polyethylene films. Agrociencia 32, 71–74.*

[c] *Diaz-Perez, J.C., Bautista, S., Villanueva, R., 2000. Quality changes in sapote mamey fruit during ripening and storage. Postharvest Biol. Technol. 18, 67–73.*

[d] *Díaz-Pérez, J.C., Muy-Rangel, M.D., Mascorro, A.G., 2007. Fruit size and stage of ripeness affect postharvest water loss in bell pepper fruit (*Capsicum annuum *L.). J. Sci. Food Agric. 87, 68–73.*

loss, commodities may be edible but their quality low (soft, wilted, shriveled, etc.) and have little commercial value.

The *epidermis* of fruits and vegetables plays a major role in the gas exchange between the produce and its surrounding air (Díaz-Pérez et al., 2007). The epidermis prevents rapid dehydration of produce by forming a layer of reduced permeability to water loss. This protection against water loss is of even greater importance after harvest, when fruits and vegetables are detached from the plant, the source of water.

Water can be transpired from produce through the *cuticle* (cuticular transpiration), stomata (stomatal transpiration), and suberized surfaces (peridermal transpiration) (Larcher, 1995). In many fruits, most of the transpiration is cuticular because fruit skin has few stomata. In some fruits, however, transpiration may occur primarily through other fruit parts, such as the calyx, as in eggplant fruit (Díaz-Pérez, 1998b).

In roots, tubers, and bulb vegetables, produce (e.g., onions, garlic, sweet potato, white potato, cassava, etc.) is submitted to *curing* before long-term storage, to induce the formation of periderm in the epidermis (Wills et al., 1998). The periderm is composed of layers of suberized cells. Immediately after harvest, onions are placed on the surface of soil for curing (drying) under field conditions. Onions can also be cured using a forced-air oven (Petropoulos et al., 2017). Cured produce has increased shelf life and reduced both transpiration and incidence of decay compared to uncured produce. A fast curing (9 days at 30°C) was found to reduce the rate of onion bulb deterioration (Eshel et al., 2014). In sweet potato, curing is done for 7 days at 29°C and 90%–95% RH (Wills et al., 1998).

8.6 MEASUREMENT OF TRANSPIRATION IN FRUITS AND VEGETABLES

The *rate of transpiration* of fruits and vegetables depends on the water vapor concentration or water vapor pressure at the evaporating surface of the produce and the diffusive resistance of all paths from inside the produce to the air.

Periodic weighing in conditions of known air VPD and air temperature is the most common method to measure transpiration of fruits and vegetables. This method assumes that all weight loss in produce derives from water loss, although some weight loss in produce may be attributed to CO_2 respirational losses. In tomato, 5% of the fruit weight loss is due to respiration (Shirazi and Cameron, 1993). The rates of water loss for various commodities have been determined (Table 8.3). However, these rates of water loss vary significantly in the literature. Values also are often expressed using different units. Additionally, some studies report water loss rates without information on the vapor pressure difference in which commodities were stored, sometimes making it difficult to compare data from various studies. Values of water loss rate in Table 8.3 are shown as a percentage of weight loss of produce per unit of vapor pressure difference (kPa) between the produce and the surrounding air.

8.7 FACTORS THAT AFFECT POSTHARVEST TRANSPIRATION

Transpiration accounts for most of the weight loss in the majority of fruits and vegetables (Burton, 1982). In tomatoes, transpiration accounts for 92%–97% of fruit weight loss (Shirazi and Cameron, 1993). Postharvest transpiration is determined by various biological and environmental factors (Fig. 8.2).

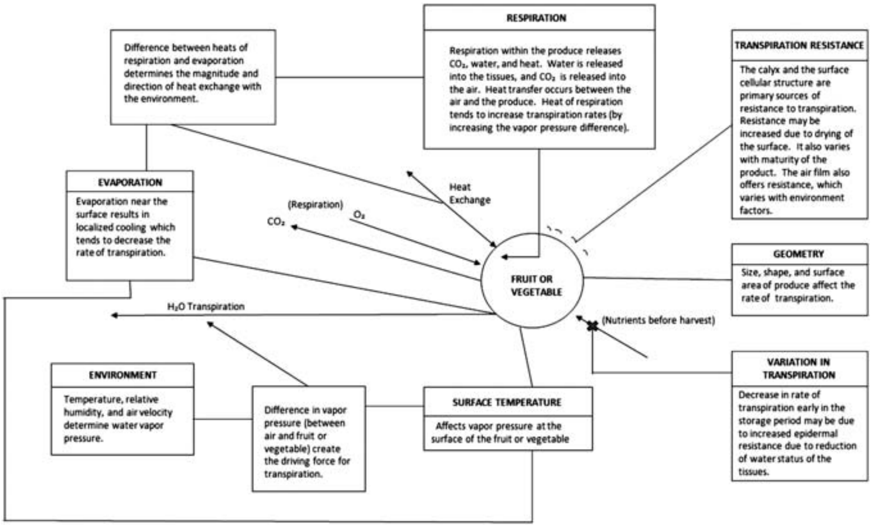

FIGURE 8.2

Factors that determine postharvest transpiration in fruits and vegetables. *Adapted from Sastry, S.K., Baird, C.D., Buffington, D.E., 1978. Transpiration rates of certain fruits and vegetables. ASHRAE Trans. 84, 237–255.*

8.8 ENVIRONMENTAL FACTORS

Temperature and *RH* are the most important environmental factors that determine the postharvest life of commodities (fruits and vegetables). In postharvest handling, emphasis has been on temperature management (cooling) as a means to reduce produce transpiration and thus extend produce shelf life. *Wind speed* as in controlled-temperature rooms may also influence transpiration of commodities. The type of packaging used may influence the wind speed to which produce is exposed.

8.9 BIOLOGICAL FACTORS

8.9.1 Fruit Size

Fruit transpiration decreases with increasing fruit size. This response has been found in tomato, bell pepper, and eggplant (Díaz-Pérez, 1998b; Díaz-Pérez et al., 2007; Lownds et al., 1993). The effect of fruit size on fruit transpiration rate may be of commercial importance due to the direct impact of transpiration on reducing sealable fruit weight and the impact on decreasing fruit shelf life. In eggplants, fruit of commercial size-32 (180 g/fruit) was found to have a transpiration rate of 1.12%/day/kPa compared to fruit size-16 (550 g/fruit) with a rate of 0.62%/day/kPa (Díaz-Pérez, 1998b). Because of these differences in transpiration rate, smaller eggplant fruit become shriveled and have a shorter shelf life compared to larger eggplant fruit.

8.9.2 Surface Area/Weight Ratio

The commodity transpiration rate is directly proportional to its surface area (Burton, 1982). For commodities of similar shape, the surface area/weight ratio decreases as the commodity increases in size (Fig. 8.3). A similar response is obtained when relating transpiration with surface area/volume ratio. In eggplants, small fruits had increased surface area/weight ratio and increased fruit transpiration rates relative to large fruits (Díaz-Pérez, 1998b). In different tomato lines, fruit water loss was found to be related to fruit surface area/volume ratio (Bouzo and Gariglio, 2016). Thus, when comparing fruits of different sizes and cultivars it is necessary to express fruit transpiration on a per surface area basis to normalize for differences in surface area/weight among fruit.

8.9.3 Stage of Development/Maturity Stage

The maturity stage may influence the transpiration rate of the commodity. As commodities develop, the transpiration rate may change in response to their increased size and decreased surface area/weight ratio, as well as by the morphological transformations, such as changes in cuticle thickness and composition. Eggplant is one example of how several factors may participate to reduce fruit water loss as fruit develop (Díaz-Pérez, 1998b). Eggplant fruit have decreased surface/weight ratio with increasing fruit size. Eggplant fruit are partially covered by an enlarged calyx. This calyx is a major route for transpirational water loss. The rate of water loss through the calyx is higher than through the fruit, and the proportion of eggplant fruit covered by the calyx decreases with increasing fruit size. In tomato, fruit at the red stage was found

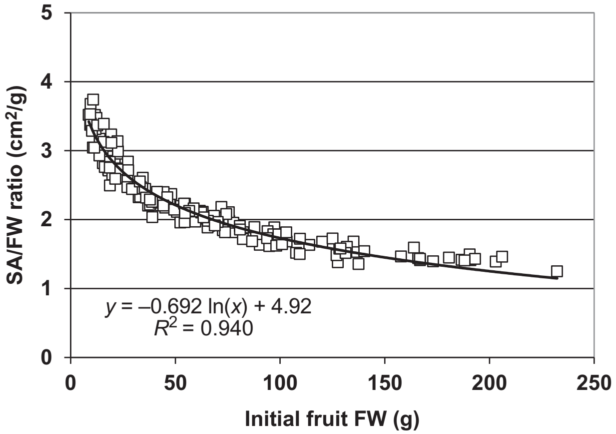

FIGURE 8.3

Relationship of bell pepper fruit surface area/fresh weight (SA/FW) ratio to initial fresh weight (FW). Each point represents an individual fruit. *After Díaz-Pérez, J.C., Muy-Rangel, M.D., Mascorro A.G., 2007. Fruit size and stage of ripeness affect postharvest water loss in bell pepper fruit (Capsicum annuum L.). J. Sci. Food Agric. 87, 68–73.*

to have a higher transpiration rate than fruit at the mature-green stage (Díaz-Pérez and Araiza, 1997). Whether a produce is climacteric or nonclimacteric may also affect its susceptibility to water loss. In nonclimacteric produce, RH (high) may have a stronger effect on delaying produce deterioration than temperature (low) (Lurie et al., 1986). Thus, reducing water loss particularly in nonclimacteric produce is an important factor affecting postharvest life.

8.9.4 Epidermis (Skin)

The exterior surfaces (skin) of leaves, stems, flowers, and fruits are covered by a waxy, relatively impermeable, layer called the *cuticle* (Kramer and Boyer, 1995). This skin plays an important role in gas exchange between the commodity and the environment. The skin allows the commodity to maintain a high water content despite low air humidity values around the commodity. For example, tomato fruit have a moderately thick waxy cuticle with no pores (Wilson and Sterling, 1976). Cuticles are more impermeable to water when dry than when they are wet. The cuticle is typically thinner on leaves grown under shaded and well-irrigated conditions than under sunny and soil water-limiting conditions. In bell pepper grown under different levels of shade, however, fruit transpiration was unaffected by shade level (Díaz-Pérez, 2014). This apparent inconsistency may be because cuticle permeability to water vapor diffusion may not necessarily depend on cuticle thickness or degree of wax coverage, but on the cuticle chemical composition (Kerstiens, 2006). In tomato, cuticle thickness was found not to explain the differences in fruit transpiration among several tomato lines (Bouzo and Gariglio, 2016).

8.9.5 Injuries, Wounds, and Cracks

Tissue wounds caused by disease or mechanical injury may increase the transpiration rate of commodities. In laboratory drop tests, impacted oranges were found to have a fruit transpiration rate 0.5% higher than the control (Miranda et al., 2015). In addition to causing increased transpiration, tissue wounds may be a route for penetration of pathogenic microorganisms into fruits and vegetables.

The presence of cracks in commodities is usually associated with increased transpiration. Cracking is common in many produce, such as sweet cherries and tomatoes. Tomato fruit cracking is frequent in fruit that have a thin skin, such as heirloom cultivars (Fig. 8.4).

8.9.6 Presence of Leaves, Stems, Flowers, or Calyx Attached to Commodities

The transpiration rate in commodities may increase when the commodity is attached to plant parts (leaves, stems, peduncles, flowers, etc.) that have a high transpiration rate (Fig. 8.5). The contribution of leaves and stems attached to produce transpiration is often not fully understood. There seems

FIGURE 8.4
Fruit cracking in heirloom tomatoes.

FIGURE 8.5
Bunched onions and carrots have a shorter shelf life and a higher transpiration rate compared to onions and carrots whose leaves have been removed.

to be a functional two-way hydraulic connection (predominantly through xylem) between the produce and its attached organs, as found in tomato and sweet cherries (Athoo et al., 2015; Windt et al., 2009). This xylem connection allows water movement from the produce (e.g., carrot root) to the highly transpiring organs to which the produce may be attached (e.g., leaves), resulting in increased produce water loss. Personal observations indicate that bunch carrots, bunch onions, and bunch tomatoes wilt faster compared to the same produce detached from leaves and stems (Fig. 8.5).

In sweet cherries (*Prunus avium*), the peduncle is an indicator of fruit freshness for marketing purposes. Shriveled and brown pedicels occur because of water loss from the peduncle (Drake and Elfving, 2002). In cherries, it is possible that water may move from the peduncle to the fruit.

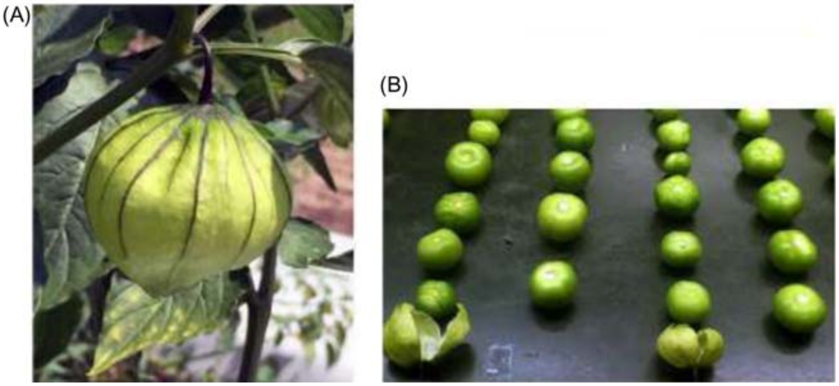

FIGURE 8.6

(A) Fully developed tomatillo (*Physalis ixocarpa*) fruit before harvest. (B) Tomatillo fruit kept 7 days at 20°C and 70% RH; fruits on rows 1 and 3 (left to right) were kept with the husk intact, covering the fruit, while fruits on rows 2 and 4 were kept without their husk. The presence of husk on fruit resulted in enhanced fruit shriveling.

Tomatillo (*Physalis ixocarpa*), also called "husk tomato," is a popular fruit in Mexico and Guatemala. Tomatillo fruit is covered by an accrescent calyx (husk) (Fig. 8.6). This husk remains attached to the fruit during fruit development. Commercially, tomatillos are typically sold with their calyx attached. I have found (unpublished data) that tomatillo fruit without the husk has a significantly reduced fruit transpiration relative to fruits attached to their husk. Thus, removing tomatillo husk will probably reduce fruit water loss in tomatillo and may help prolong its postharvest life.

The stem scar is a major pathway for transpiration in tomato and other fruit (Yang and Shewfelt, 1999). It has been reported that there is a positive correlation between the surface area of the stem scar to the fruit surface area ratio and water loss of the tomato fruit (Bouzo and Gariglio, 2016). Tomato may be jointed-stem or jointless-stem (Zahara and Scheuerman, 1988). The calyx and stem of jointless cultivars usually remain attached to the plant when the fruit is harvested. The stem of jointed cultivars typically separates from the plant at the stem joint, so that the stem and calyx remain attached to the harvested fruit. The harvester then has to remove the stem and calyx from the fruit to prevent injury to other fruit in the containers. Such punctures of the fruit may lead to fruit decay. Although jointless cultivars may have increased fruit transpiration rates, these cultivars provide considerable economy in picking time. With the increased efficiency of picking jointless over jointed cultivars, a crew can harvest more fruit in a day and reduce injury to tomato fruit and plants. Although sealing of the stem scar with lanolin, petrolatum, or other lipids may reduce fruit water loss, doing so may diminish diffusion of oxygen and carbon dioxide, resulting in fermentation of the fruit. In blueberries, the stem scar accounts for about 40% of fruit transpiration and the water loss rate through the stem scar is 170 higher than through the cuticle. The influence of the stem scar on water loss was found to increase as temperature declines (Moggia et al., 2017).

In eggplant (*Solanum melongena*) the fruit calyx is the main route for fruit water loss, accounting for at least 60% of fruit transpiration (Díaz-Pérez, 1998b). In some countries, such as Japan and Israel, the greenness and freshness of the calyx is an important fruit quality attribute. Thus, postharvest treatments are necessary to maintain the health and freshness of the calyx to extend shelf life (Temkingorodeiski et al., 1993).

8.9.7 Cultivars

The transpiration rate may vary among cultivars of the same crop. This difference may be due to differences in permeance of the epidermis or to differences in surface area/weight ratio as a result of differences in size or shape. In blueberries, the water permeance of the fruit cuticle was found to vary twofold and the apparent permeance of the scar to vary threefold among nine lines. One line exhibited a 75% lower rate of water loss from its stem scar than the other lines than would be predicted based on its scar diameter (Moggia et al., 2017). In tomato, fruit transpiration was found to vary among 10 different tomato lines and the differences were attributed to differences in surface area/volume of fruit (Bouzo and Gariglio, 2016).

8.9.8 Storage

The transpiration rate of commodities often declines over time after harvest. In tomato, after a 14-day storage period, transpiration was reduced by 50% of its initial value (Díaz-Pérez and Araiza, 1997). The causes of this reduced transpiration rate are probably due to increased resistance to water movement inside the commodity from the commodity to the outside air as the commodity dehydrates. In blueberry, cuticle permeance was found to be unaffected by temperature (Moggia et al., 2017). The cuticle characteristics may change over storage thus affecting fruit transpiration of fruit, as in apples (Fig. 8.7).

8.10 CONTROL OF TRANSPIRATION

8.10.1 Storage

Low temperature reduces the vapor pressure difference between the commodity and the surrounding air. A combination of high-RH and low-temperature storage is more effective in extending shelf life compared to only using low-temperature storage.

8.10.2 Surface Coatings

Surface coatings (waxes, edible films, etc.) are used to modify the internal atmosphere and to reduce water losses of fruits and vegetables (Ergun et al., 2005; Hagenmaier and Baker, 1994). The permeance values of produce treated with coatings may differ compared to the permeance of the coatings

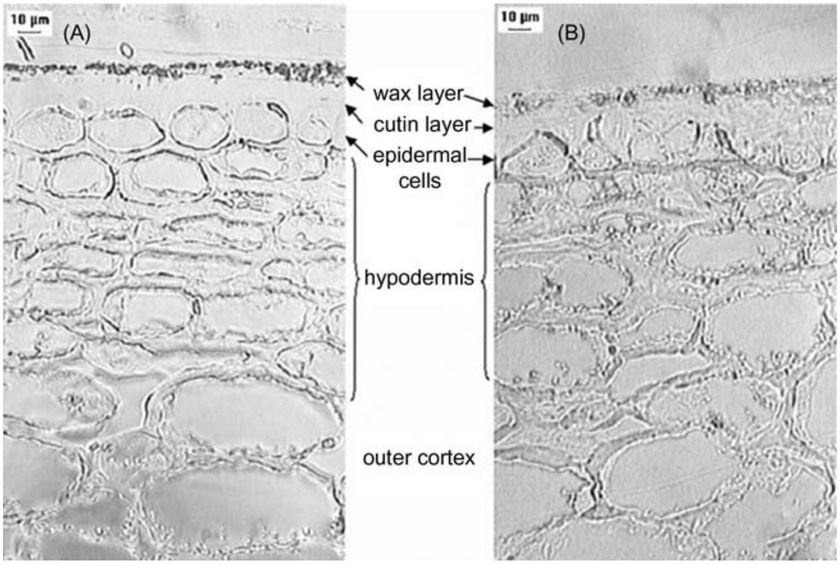

FIGURE 8.7

Cross sections of the skin and outer cortex of "Jonica" apples sampled in (A) March and (B) June, after a 3-month storage. *Photo from Schotsmans, W., Verlinden, B.E., Lammertyn, J., Nicolai B.M., 2004. The relationship between gas transport properties and the histology of apple. J. Sci. Food Agric. 84, 1131–1140.*

FIGURE 8.8

Greenhouse-grown bell pepper packed with polymeric film. The package extends fruit postharvest life by reducing fruit transpiration. The package also facilitates fruit handling and provides protection to reduce fruit mechanical damage. The package may help in marketing by allowing labeling and providing an appealing appearance of the fruit.

(Amarante et al., 2001). Coatings block the pores on the produce skin, reducing fruit water loss. Wax is commonly used in many fruits such citrus, tomato, bell pepper, and cucumber to improve fruit appearance and reduce transpiration; however, the effect of the wax on reducing fruit transpiration is limited (about 30% reduction).

8.10.3 Polymeric Films

Modified atmosphere packaging with polymeric films is effective in reducing transpiration and extending shelf life in commodities (Fig. 8.8).

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