CHAPTER

15

Physiological Disorders and Their Control

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15.1 INTRODUCTION

Physiological disorders are those that are not caused by fungal, bacterial, viral, or insect agents, but rather by physiological and/or biochemical causes. Physiological disorders can occur before or after harvest. Several physiological disorders are initiated before harvest and commonly appear until after harvest, especially during storage. The causes of these disorders are diverse and include temperature (low or high), mineral imbalance, chemicals including ethylene, wind, hail, and some agricultural practices, among others.

15.2 PHYSIOLOGICAL DISORDERS RELATED TO ENVIRONMENTAL FACTORS

15.2.1 Low Temperatures

Temperature is one of the most important environmental factors that regulate plant growth and development. Temperature control is the most important postharvest practice for the handling of perishable horticultural commodities. The different horticultural commodities respond differently to different temperatures, especially based on the origin of these commodities (tropical, subtropical, or temperate). Deviation from optimum temperatures can be a source of stress and injury.

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15.2.1.1 Freezing

Freezing results when commodities are held below their freezing temperatures, either before or after harvest, could lead to the collapse of the tissue. The temperature at which products freeze (below 0°C) is a function of the concentration of dissolved solutes (e.g., sugars) within the tissue and cells. Pure water freezes at 0°C, a product such as lettuce, which is mostly water, freezes at approximately −0.2°C, and in contrast, products with high solute/sugar contents (e.g., carrots and sweet potatoes) freeze at about −1.8°C. The ranges of temperatures at which some fruits and vegetables freeze are −2.2°C to −1.7°C in apples, −1.8°C to −1.7°C in potatoes, −0.9°C to −0.8°C in cucumbers, and −0.6°C to −0.3°C in lettuce.

The disruption caused by freezing usually results in the collapse of the tissues and may lead to total loss of the commodity. When products freeze, water forms into ice crystals within and between the cells, resulting in the dehydration of the cells themselves. Expanding ice crystals can also pierce the cell walls. When the product thaws the cells collapse, resulting in the water-soaked appearance and loss of structural integrity typical of freezing injury. Freezing renders the commodities unable to resume normal metabolic activities. More severe freezing damage is most likely when the commodity freezes slowly, resulting in the formation of larger ice crystals. Food processing facilities producing frozen fruits and vegetables rely on rapid blast freezers to limit the size of ice crystals and reduce the damage to the integrity of the frozen product.

Certain vegetables like cabbage have some tolerance to freezing and can recover if defrosted slowly and for a shorter period of time. The ideal method to avoid freezing injury is to always maintain fresh horticultural commodities at higher-tier freezing temperatures.

15.2.1.2 Chilling Injury

Chilling injury (CI) is different than freezing injury in that it occurs above freezing temperatures at a range of temperatures of 0–15°C. CI disorders and symptoms (Figs. 15.1–15.8) include the collapse and necrosis of tissue, pitting, water soaking, loss of flavor and aroma, increased susceptibility to decay, and finally the death of the tissue. CI has a great economic importance because chilling sensitive crops cannot be maintained at low temperatures being the most important postharvest technique for the proper handling of perishable horticultural commodities. They are therefore usually stored for a shorter period of time, and their qualitative and quantitative losses are high, compared to the chilling resistant commodities. Most commodities of temperate origin are resistant to CI (Table 15.1). All commodities of tropical origin and many commodities of subtropical origin are chilling sensitive (Table 15.2). CI is cumulative and usually appears after about 2 days at room temperature following low temperature storage. Fig. 15.2A exhibits avocado fruit stored for 39 days at 4°C + 5 days at 25°C, showing pulp darkening mainly around the vascular tissues. Avocados need a few days of storage at ambient temperatures to reveal the injury, whereas lemons required 2 weeks at 4°C (Fig. 15.2B) to exhibit evident injury on the peel. On the other hand, banana peels require 2 days at 4°C to show browning, but require 7 days to exhibit pulp darkening (Figs. 15.1A and B).

CI is of great economic importance for horticultural commodities, taking in consideration that the cold chain is the most important postharvest strategy to preserve these commodities.

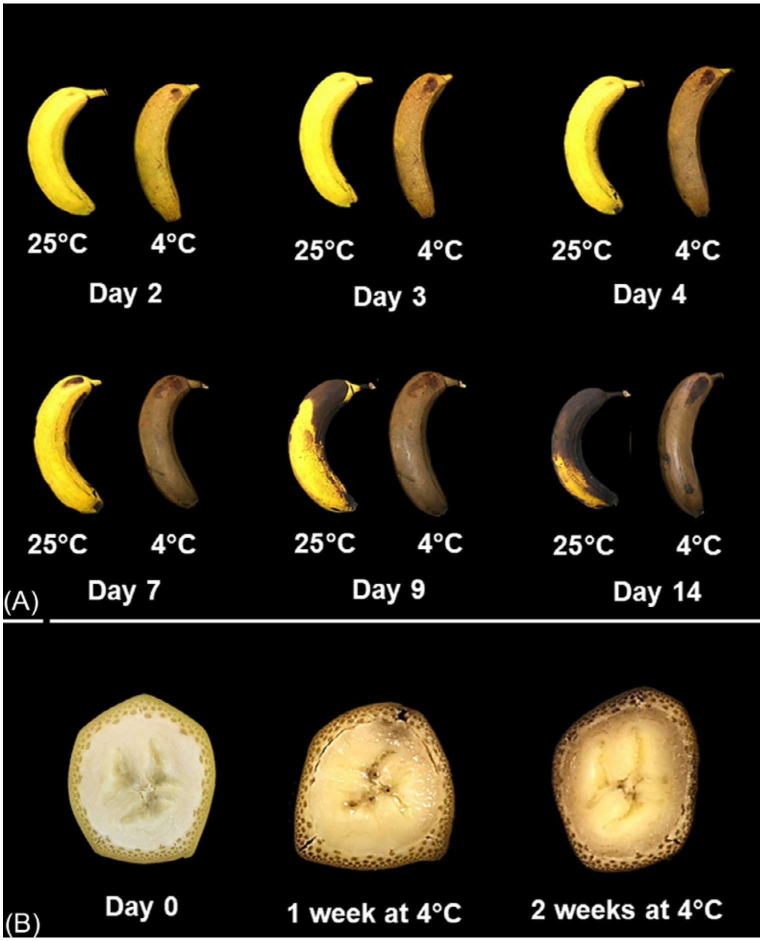

FIG. 15.1 External (A) and internal (B) injury chilling injury in banana fruit exposed to 4°C for up to 2 weeks.

Therefore the many chilling sensitive commodities cannot be maintained at very low temperatures; thus they cannot be maintained for a very long period of time, and their losses are commonly high.

Several causes have been suggested for CI; among the most important is a phase transition of membrane lipids from liquid to a crystalline state. This phase change modifies the activation energy of lipid-associated respiratory enzymes, among other metabolic effects.

Several factors affect CI including maturity (ripe fruits are less sensitive), atmosphere modification, relative humidity, and some minerals and chemicals, among other factors.

CI injury is prevented with the use of optimum (above critical) temperatures and can be ameliorated with intermittent warming, high CO_2 atmospheres (if tolerated by the tissue), high relative humidity, heat treatments, and applications of certain chemicals, such as the fungicide thiabendazole, among other factors, as will be described later.

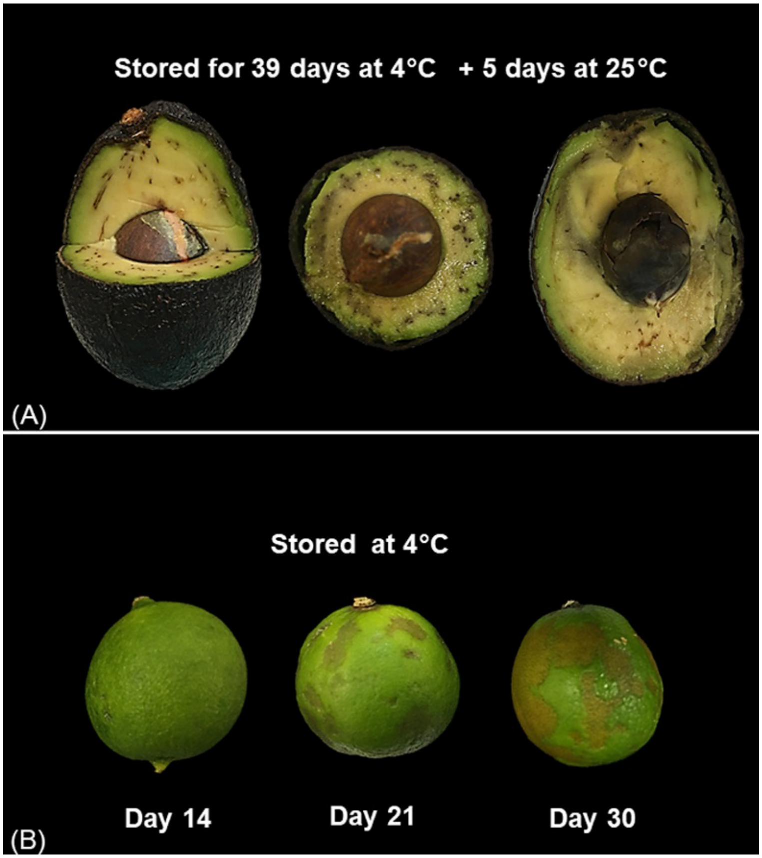

FIG. 15.2 Chilling injury in avocado fruit stored at 4°C for 39 days (A) and limes at 4°C for 14, 21, and 30 days (B).

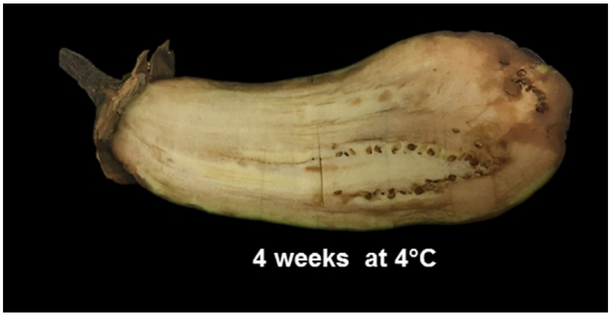

FIG. 15.3 Internal chilling injury in eggplant stored at 4°C for 4 weeks.

FIG. 15.4 External chilling injury on eggplant.

FIG. 15.5 Internal chilling injury on avocado fruit.

FIG. 15.6 Chilling injury on cucumbers.

FIG. 15.7 Chilling injury on Fortune mandarin. *Courtesy of Prof. Ahmed Ait-Oubahou.*

FIG. 15.8 Chilling injury on peppers.

TABLE 15.1 Examples of crops insensitive to chilling injury and their optimum holding temperatures

Fruits	Temperature (°C)	Vegetables	Temperature (°C)
Apricots	−0.5–0	Beets	0
Blueberries	−0.5–0	Broccoli	0
Cashew apple	0–2	Carrots	0
Fresh figs	−0.5–0	Celery	0
Grapes	−0.5–0	Garlic	0
Kiwifruit	0	Globe artichoke	0
Loquats	0	Lettuce	0
Peaches	−0.5–0	Onions	0
Pears (American)	−1.5–0.5	Parsley	0

TABLE 15.1 Examples of crops insensitive to chilling injury and their optimum holding temperatures—cont'd

Fruits	Temperature (°C)	Vegetables	Temperature (°C)
Pears (Asian)	1	Radishes	0
Plums and prunes	−0.5–0	Spinach	0
Sweet/sour cherries	0	Sweet corn	0
Strawberries	0		

TABLE 15.2 Examples of chilling sensitive crops and their optimum holding temperatures

Fruits	Temperature (°C)	Vegetables	Temperature (°C)
Avocado (Hass)	3–7	Bell pepper	7–10
Bananas	13–15	Cucumber	10–12
Cherimoya	13	Eggplant	8–12
Grapefruit	10–15	Ginger	13
Guavas	5–10	Hot peppers	5–10
Jackfruit	13	Melon, casaba	7–10
Lemons	10–13	Melon, crenshaw	7–10
Mangoes	10–13	Melon, honeydew	5–10
Papayas	7–13	Okra	7–10
Passion fruit	10	Summer squash	7–10
Pineapples	7–13	Tomato	7–13
Plantains	13–15	Sweet potato, yam	13–15
Pommelo	7–9	Winter squash	12–15
Rambutan	12	Water melon	10–15
Sapodilla	15–20		
Sugar apples, custard apples	7		
Yams	15		

CHILLING INJURY SYMPTOMS

CI injury symptoms commonly appear after maintaining the commodity at ambient temperature after exposure to chilling temperatures for a sufficient period of time, which varies depending on the sensitivity of the commodity to CI. These may include the following:

1. Failure of the fruit to ripen. A good example is a mature green tomato when kept in refrigeration for few days.
2. Softening of the fruit, common in all sensitive crops.
3. Loss of flavor and aroma, most easily observed in guavas maintained at 8°C or less for a few days.

4. Increased sensitivity to decay in all sensitive crops.
5. Browning of the skin (such as in bananas) or internal browning.
6. Off-flavor production in several fruits and vegetables.
7. Pitting.
8. Water-soaked areas.

FACTORS AFFECTING THE SYMPTOM DEVELOPMENT OF CHILLING INJURY

1. *Temperature*. Under unsafe temperatures: the lower the temperature, the greater the severity of the symptoms.
2. *Time*. Under unsafe temperatures: the longer the exposure period, the greater the severity of the symptoms. However, crops can recover from short exposures to unsafe temperatures.
3. *CI is cumulative*. The time of exposure to chilling unsafe temperatures before harvest is cumulative to postharvest exposure.
4. Symptoms may not appear until the removal of produce to ambient temperature.

In most cases the reactions related to symptom development are inhibited at low temperatures, but will progress and appear at ambient temperatures.

FACTORS THAT AFFECT CHILLING INJURY

Internal (concerning to the produce)

1. *Genetics*. Different species, and in some cases even different cultivars of the same species, may differ in degree of chilling sensitivity.
2. *Stage of maturity*. Chilling sensitivity decreases with maturation and ripening.

External (concerning to the environment surrounding the produce)

1. *Acclimation*. Exposure to low but safe temperatures for short periods of time.
2. *Exposure to high temperatures previous to chilling temperature exposure*. For example, 2 days in air at 38°C or 10 min in water at 53°C may increase the resistance of some fruits to CI.
3. *Intermittent warming*. This may increase the resistance to CI, and it is believed to also promote the detoxification of toxic compounds that result in the injury.
4. *High relative humidity during storage*. This slows water loss and decreases the development of pitting.
5. *Modified (MA) and controlled atmospheres (CA)*. MA/CA, especially high concentrations of CO_2, have shown to ameliorate CI of several fruits such as avocados, mangoes, and grapefruit.
6. *Some fungicides*. Thiabendazole has been known to alleviate CI when applied to grapefruit.

METHODS FOR THE ASSESSMENT OF CI

Some methods have been developed for the assessment of CI in horticultural commodities.

CHLOROPHYLL FLUORESCENCE Chlorophyll fluorescence measurements by pulse-amplitude modulation have been used to assess the extent of CI in several tissues. CI symptoms on basil leaves stored at unsafe chilling temperature correlate positively with changes in the nonphotochemical quenching coefficient (qNP), whereas the photochemical quenching coefficient (qP) do not. Basil leaves can be safely stored at 12°C; however, they show CI symptoms after 4 days of storage with moderate damage at 8°C and severe damage at 4°C. Changes in qNP can be easily measured by means of a chlorophyll fluorometer.

Storage at low, unsafe temperatures has been known to provoke damage to the photosystem II, which has been associated with a phase transition occurring in the lipids of the thylakoid membranes. Photosystem II damage has been regarded as a suitable indicator of damage provoked by chilling temperatures on thylakoid membranes of apples and cucumbers. CI development has been also evaluated by the chlorophyll fluorescence technique during storage of bananas, mangos, and green peppers at low temperatures. This technique as a nondestructive determination may provide a rapid, sensitive, and practical estimation of the chilling damage of fruits and vegetables. It can detect CI even before the appearance of visual CI symptoms and even in those fruits that are thought to contain insufficient amounts of chlorophylls, such as mature apples.

ION LEAKAGE Relatively long exposures of sensitive fruits and vegetables to unsafe chilling temperatures may provoke the disruption of their cell membranes with the consequent loss of their semipermeable nature leading to ion leakage. Due to this fact, ion leakage measurements have been widely used to assess CI in sensitive plant tissues subjected to low-temperature stress. The loss of the membrane semipermeable nature leading to ion leakage may be the result of two mechanisms: (1) directly by phase transition in the membrane lipids and (2) indirectly by oxidative stress. The phase transition in lipid membranes is from a liquid-crystalline phase to a gel phase leading to the separation of phases that leads to increased membrane leakiness. On the other hand the oxidative stress is the result of an induction of the dysfunction of enzymes along with a redistribution of cellular calcium leading to an accumulation of reactive oxygen species (ROS) able to oxidize cell membranes and promote the disruption of the membrane bilayer structure.

CI INDEX CI can be subjectively determined by means of a visual assessment of the damage on peel tissue. Symptoms of damage such as pitting, water soaked areas, and decay are often used to assess CI. This approach is frequently employed in routine assessments of product damage.

The visual assessment of injury for the levels of different symptoms can be scored according to a certain scale, such as the following:

0 = No damage (ND).
1 = Very slight damage (VLD, < 5% area affected).
2 = Slight damage (LD, 6%–10% area affected).
3 = Moderate damage (MD, 11%–25% area affected).
4 = Severe damage (SD, 26%–50% surface affected).
5 = Very severe damage (VSD, >50% surface affected).

The CI index for a batch of fruits or vegetables is then calculated using the following formula:

$$\text{CI index} = (1^*\text{NDF}_{\text{VLD}}/\text{TDF}) + (2^*\text{NDF}_{\text{LD}}/\text{TDF}) + (3^*\text{ND}_{\text{MD}}/\text{TDF}) + (4^*\text{NDF}_{\text{SD}}/\text{TDF}) + (5^*\text{NDF}_{\text{VSD}}/\text{TDF}).$$

where NDF_{VLD} = (Number of fruits showing VLD by pitting) + (Number of fruits showing VLD by water-soaked areas) + (Number of fruits showing VLD by decay) + (Number of fruits showing VLD of other type of symptom(s), if any); NDF_{LD} = (Number of fruits showing LD by pitting) + (Number of fruits showing LD by water-soaked areas) + (Number of fruits showing LD by decay) + (Number of fruits showing LD of other type of symptom(s), if any); NDF_{MD} = (Number of fruits showing MD by pitting) + (Number of fruits showing MD by water-soaked areas) + (Number of fruits showing MD by decay) + (Number of fruits showing MD of other type of symptom(s), if any); NDF_{SD} = (Number of fruits showing SD by pitting) + (Number of fruits showing SD by water-soaked areas) + (Number of fruits showing SD by decay) + (Number of fruits showing SD of other type of symptom(s), if any); NDF_{VSD} = (Number of fruits showing VSD by pitting) + (Number of fruits showing VSD by water-soaked areas) + (Number of fruits showing VSD by decay) + (Number of fruits showing VSD of other type of symptom(s), if any).

TDF is the number of damages accumulated from all the levels of damage of all the types of symptoms:

$$TDF = NDF_{VLD} + NDF_{LD} + ND_{MD} + NDF_{SD} + NDF_{VSD}.$$

AMELIORATION OF CI

Several approaches have been applied to ameliorate the injury provoked by maintaining the commodities at unsafe low temperatures. The techniques may attain this purpose by either increasing the produce tolerance to chilling temperature or by delaying the CI symptoms development. They may involve the modification of the storage environment or by treating the commodity chemically. Some of these techniques include temperature conditioning, intermittent warming, modified and controlled atmospheres, chemical treatments, and growth regulator applications.

TEMPERATURE CONDITIONING The commodity tolerance to CI can be increased by applying temperature conditioning treatments, which consist of exposing the produce during a short period to temperatures slightly above the chilling low temperatures. Some tropical and subtropical commodities (e.g., cucumbers, eggplants, grapefruit, lemons, limes, mangos, papayas, sweet peppers, tomatoes, and zucchini squash) have shown an increased tolerance for CI after being exposed to treatments of temperature conditioning. These can be applied as single- or multistep treatments, with the later being more effective. The level of pitting in eggplant after storage at 6.5°C is reduced to a greater extent when the eggplant is previously conditioned at 15°C for 2 days followed by 1 day at 10°C than when only conditioned at 15°C for 2 days. CI is reduced in bananas with multistep treatments by gradually decreasing the temperature from 21°C to 5°C in 3°C each 12 h, in 5°C every 24 h, in 8°C every 36 h, or directly from 21°C to 5°C. The highest CI reduction is observed in the treatment of a 3°C decrease every 12 h. Relatively high temperatures of conditioning (38°C) can also be applied as a prestorage conditioning treatment to reduce CI. For example the pitting degree is reduced when grapefruits are exposed at 38°C for 17–22 h before stored at 4.5°C. High-temperature conditioning also benefits some other chilling-sensitive fruits and vegetables, such as cucumbers, lemons, mangos, sweet potatoes, tomatoes, and watermelons. Furthermore, high-temperature treatments for sweet potatoes (a process known as curing) result in wound healing, reduced moisture loss, and protection against pathogens during storage.

INTERMITTENT WARMING Intermittent warming consists of the interruption of storage at chilling unsafe temperatures with one or more steps of moderate warming. This approach has shown a CI reduction when applied to some fruits (e.g., lemons) when the fruit is stored at 2°C, and then every 21 days the fruit is exposed to 7-day periods of warming at 13°C. Following this approach, lemons are able to keep their market quality for at least 6 months. The timing and frequency for applying intermittent warming depends on how short or long is the postharvest life of the commodity. Furthermore, this approach should be applied when CI phenomenon can still be reversed, otherwise the warming will accelerate the symptoms development. Crops with a short postharvest life will require treatments that should be applied earlier and more frequently; such is the case for cucumbers and sweet peppers.

MODIFIED ATMOSPHERES AND CONTROLLED ATMOSPHERES Modified atmospheres (MA) and controlled atmospheres (CA), with low-oxygen and high carbon dioxide pressures, have been known to reduce CI symptoms, although the effect is not consistent. Depending on the produce, the CI reduction effect can be beneficial, null, or detrimental. Avocados, grapefruit, okra, pineapples, and zucchini squash show benefits. Lemons, papayas and tomatoes show null effect, whereas cucumbers, limes, and sweet peppers show detrimental effects. The effect is probably due to the high levels of carbon dioxide pressures.

CHEMICAL TREATMENTS A variety of chemical compounds with varied chemical structures have been known to be effective in reducing CI. Some of these compounds include calcium, ethoxyquin, sodium benzoate, imazalil (1-(2-(2,4-dichlorophenyl)-2-(2-propenyloxylethyl)-1H-imidazole)), thiabendazole (2-(4-thiazolyl) benzimidazole), mineral oil, safflower oil, vegetable oil, and squalene. The CI-reducing effect for most of them is based on the compound properties needed to maintain the integrity of cell membranes. CI is reduced by calcium in avocados, okra, and tomatoes by apparently strengthening cell wall and membranes. CI is reduced by ethoxyquin and sodium benzoate in cucumbers and sweet peppers by scavenging free radicals and thus reducing peroxidation of membrane lipids. Pitting is reduced by the fungicides imazalil and thiabendazole in oranges and grapes, besides inhibiting latent infections and delaying peel senescence. The underpeel discoloration of bananas, as a consequence of its exposure to unsafe low temperatures, is prevented by mineral and safflower oils. CI development is delayed by vegetable oil in grapefruits. It is believed that oils are able to reduce CI by reducing moisture loss and oxidative stress. CI can also be reduced by applying squalene on grapefruit peels, although squalene is a waxy component naturally occurring in grapefruit peels.

GROWTH REGULATORS Plant growth regulators such as abscisic acid (ABA), ethylene, polyamines, and several triazole-derived compounds have shown an ability to alter the chilling tolerance of plant tissues. ABA applications have suppressed ion leakage and reduced CI of grapefruit and zucchini squash. Ethylene treatments reduce CI in honeydew melons, although the opposite effect can also be observed in avocados. Several triazole-derived plant growth regulators such as paclobutrazol (b-[(4-chlorophenyl)methyl]-a-(1,1-dimethyl)-1H-1,2,4-triazole-1-ethanol), uniconazole (*E*-(p-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl)-1-penten-3-ol), and triadimefon (1-(4-chlorophenoxy)-3,3-dimethyl-1-(1,2,4-triazol-1-yl)-2-butanone) have shown an increased tolerance of plants to CI. Postharvest treatments with exogenous polyamines reduce CI in zucchini squash.

FIG. 15.9 Sun burn damage on fruit before harvest.

15.2.2 High Temperatures

15.2.2.1 Heat Injury

Heat injury can occur in the field (before harvest, Fig. 15.9) or after harvest. The exposure of horticultural commodities to high temperatures, such as during exposure to direct sunlight or during (nonrefrigerated) storage or transport, can increase their temperature very significantly and cause major qualitative and quantitative losses. Temperature abuses during postharvest handling are common challenges for many products at different levels of the postharvest chain, such as during the waiting time after harvest, before cooling, before packing, during shipping, during marketing, etc. Breaks in the cold chain can lead to very high temperatures and heating and can result in major stress and injury. Temperatures higher than the optimum will increase the metabolic activity and will shorten the life of the fruit, as well as other major qualitative and quantitative losses. Heat injury symptoms include bleaching, surface burning or scalding, uneven ripening, excessive softening, and desiccation.

Several fruits will fail to ripen after exposure to 35–40°C due to the inhibition of ethylene synthesis at these temperatures. Very high temperatures will cause the death of the tissue.

Heat stress affects the stability of various proteins, membranes, RNA species, and cytoskeleton structures, as well as alters the efficiency of enzymatic reactions in the cell, causing a metabolic imbalance. The disruption of the steady-state flux of metabolites can cause the accumulation of toxic compounds, such as reactive oxygen species (ROS). Plants reprogram their transcriptome, proteome, metabolome, and lipidome as a response to heat stress. These changes establish a new steady-state balance of metabolic processes that can enable the organism to function at the new temperature, which may also be helpful in responding to other types of stress, such as low temperatures.

High temperature treatments (in air or in water) have been developed and integrated into the postharvest handling chain for different commodities for various purposes, such as reducing pathogen inoculum, controlling insect pests, and reducing chilling injury symptoms. The treatment times and temperature range vary widely, from days at 35–40°C in air to less than a minute in water at 63°C. Some treatments that have commercial approval for insect control involve either vapor heat or hot water immersion of the fruit until the core temperature reaches a certain temperature, which can take several minutes in water up to few hours in air. Hot water treatments at 46.1°C for 65–110 min are commonly used to disinfect mangoes from fruit flies. Treatments involving the use of hot water dips (HWT) for 3–20 min at 48–56°C are used to control decay. Very short (10–25 s) treatments of hot water rinsing and brushing (HWB) at temperatures of up to 63°C have also been used. These treatments may have effects on the fruits or vegetables beyond their stated purpose, as a high temperature stress can trigger changes in plant tissues affecting different physiological and biochemical processes. Some of these processes include the inhibition of ethylene production and other ripening and senescence related processes, induction of defense compounds against pathogen attack, and induction of resistance to other types of stress, including low temperature stress.

15.2.3 Disorders due to Toxic Chemicals

Several chemical compounds may cause physiological disorders in fresh horticultural commodities. The chemicals may provoke tissue death and induce the development of dark spots on produce surfaces. Some examples of these chemicals include chlorine, ammonia, SO_2, methyl bromide, and Ca_2Cl.

15.3 PHYSIOLOGICAL DISORDERS RELATED TO MINERAL IMBALANCE

15.3.1 Mineral Deficiency Disorders

Changes in postharvest life and physiology as affected by mineral imbalances in horticultural commodities might be understood from two implications: (1) the consequence of homeostasis loss in metabolic and structural processes of fruit that affects fruit quality and (2) disease sensitivity that can induce the biological acceleration of infection and decay. The diagnostics of mineral imbalances causing postharvest physiological disorders that affect the quality of horticultural commodities are difficult to recognize. The prevention and control of these disorders might be achieved when the nutrition is continuously supplied at an appropriate rate to meet the plant growth demands, synchronizing with the prevailing environmental conditions. Plants have the ability to build biogenic molecules essential for structural and functional purposes due to their powerful adaptation machinery. However, when the imbalances cross the critical level of adaptability, neither morphological nor physiological responses are enough to interrupt metabolic disorders. Several disorders due to nutrient deficiency can appear in horticultural commodities before or after harvest.

15.3.1.1 Disorders due to Calcium and Boron Deficiencies

Some of the common disorders due to calcium deficiency include fruit cracking (Figs. 15.10 and 15.11), bitter pit (Fig. 15.12), cork spot (Fig. 15.10), blossom-end rot and blackheart (Table 15.3). Other disorders associated to calcium deficiency are blossom-end rot in watermelon (Fig. 15.13), brown heart of escarole and blackheart of celery. Calcium is an essential nutrient in plants required for several metabolic and structural processes for the proper functioning of cell wall, cell membrane, vacuole, and cytosol components. Calcium, as other nutrients, is absorbed by roots and translocated through the xylem via the transpiration stream.

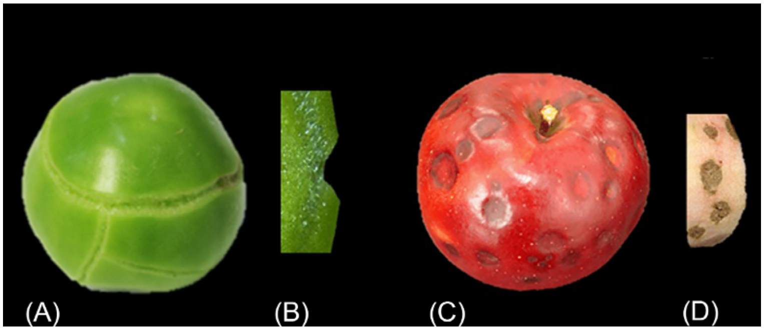

FIG. 15.10 Fruit cracking on tomato skin, external view (A) and cross-section view (B); and cork (spot like) of apple on skin (C) and in pulp (D). *Courtesy of Rosabel Vélez de la Rocha.*

FIG. 15.11 Figs skins cracking. *Courtesy of Prof. Ahmed Ait-Oubahou.*

FIG. 15.12 Bitter pit on apples.

FIG. 15.13 Low-calcium disorder on watermelon.

TABLE 15.3 Some physiological disorders of some fruits and their characteristic symptoms

Disorder	Principal affected commodity	Illustration of the disorder
Fruit cracking	Tomatoes, husk tomatoes, pomegranates, lychee, chilis, plums, prunes, apricots, peaches	
Cork (spot-like)	Apples, pears	

Continued

TABLE 15.3 Some physiological disorders of some fruits and their characteristic symptoms—cont'd

Disorder	Principal affected commodity	Illustration of the disorder
Spongy tissue	Mangoes	
Tip-burn and internal browning	Lettuce, brussels sprouts, cabbage, cauliflower, escarole, celery	
Hollow stem	Broccoli, tomatoes	

TABLE 15.3 Some physiological disorders of some fruits and their characteristic symptoms—cont'd

Disorder	Principal affected commodity	Illustration of the disorder
Blossom-end rot	Tomatoes, peppers, squash, cucumbers, melon	
Bitter pit	Apple	
Blackheart	Cabbage, celery	

Some physiological and environmental conditions can compromise the movement of calcium as it is relatively immobile in the plant; thus short improper distribution might rapidly affect growing cells.

As boron is an important micronutrient with functions such as sugar carrier and cell wall strength, some association is maintained between this mineral and calcium. Plants might demand variable requirements of calcium concentration; thus its deficiency is determined in part by soil availability or plant condition. Calcium is a macronutrient according to the plant concentration supplies and sometimes can be momentarily inaccessible for young tissues or phloem distribution. In addition, some evidence suggests that calcium deficiency symptoms are accentuated by environmental conditions causing stresses such as watering, high temperature, and high humidity.

The fundamental cell biology behind these disorders is the key role of calcium mobility toward the organs with higher transpiration rates, affecting the mineral and water distribution up to less transpiring organs. In this context the disorder may have more influence from environmental factors than calcium management, although some kind of inherited susceptibility has been reported.

Among the physiological disorders attributed to calcium imbalance in fleshy fruits are cracking, blossom-end rot, bitter pit, cork, and spongy tissue, whereas leafy vegetables are susceptible to tipburn, brownheart, and blackheart disorders.

FRUIT CRACKING

This disorder defines the phenomenon of surface or tissue cracking in a wide range of levels that depend on varietal susceptibilities, nutritional deficiencies, and environmental conditions. Among quality disorders, fruit cracking is a prime concern where nutrient calcium status has provided insights of its involvement in the physiological process of the cellular adhesion lost. Calcium represents the most studied internal factor involved in tissue cracking, although other external factors considered as environmental conditions (e.g., drought, high temperature, excessive water, and high solar radiation) have been determined as elements for cracking resistance. The concern for its management is to have the minerals in balanced availability at the early stages of fruit formation. Boron and silicon as part of the structure of cell walls might have also been involved in cracking, although the thresholds and distribution ranges inducing the disorder have not been defined for each commodity. Control of this mineral deficiency also requires the combination of weather conditions as well as germplasm tolerant to cracking. The single incorporation of mineral amendments has been ineffective in increasing structural minerals and cracking prevention.

CORK (SPOT-LIKE) DISORDER

It is considered a deleterious flesh effect commonly associated with calcium and boron deficiency, with more marked and severe incident in the late maturing of susceptible cultivars of apples and pears. Apples affected by cork disorder (Fig. 15.10) presents quality defects (e.g., dry and withered tissue) at the time that spots turns a bitter taste and can affect fruit size; however, cork spots are thought to also increase significantly on bigger fruit. The control of cork spots requires a multicontrol approach, but calcium sprays reduce the prevalence of the disorder characterized by spots ranging from green to brown sunken lesions appearing on the surface or flesh of mature apples. The spots on the peel might simulate only external damage; however, after fruit cutting the disorder can reveal internal lesions of brown color, corky hardness, and dead tissue oriented toward the calyx, as well as cracking in severe disorders. Some cultivars of pear can also develop the disorder.

SPONGY TISSUE

The spongy tissue is an internal physiological disorder of unknown origin, causing poor quality and unacceptable off-flavor in mangoes. The fruits do not exhibit external symptoms, and the disorder is detected when cutting the fruit. Alterations of ripening (texture and color) are developed in the pulp closer to the seed, converting the tissue into a hard, less-colored pulp. The color might vary from faint yellow to brownish black, with or without air incorporated to the matrix. Among candidates causing spongy defects, calcium deficiency has been postulated by its importance in cell wall integrity; however, variations have been found when preharvest or postharvest calcium applications have increased the incidence of symptomatology. Other causes, in addition to calcium deficiency, might as a consequence be linked to this internal breakdown disorder in mangoes. Environmental influence might be a key determinant for physiological and biochemical processes associated with the breakdown. Some control has been achieved by harvesting fruits close to full ripeness, using growth retardants and triazole fungicides.

TIP BURN AND INTERNAL BROWNING

This disorder is associated with the lack of calcium in soil and the deficiency of mineral absorption and translocation to the young actively growing organs. Tip burn is presented at the margins of leaves producing visible symptoms in the growing tissues (i.e., heart leaves in lettuces). The condition of internal browning is usually visualized as a necrosis of tissues between the growing point and the exterior, where a longitudinal cut is needed to confirm the severity of symptoms. This internal disorder is also related to boron deficiency, and failures to discern among minerals by symptomatology have been found. The affected tissue may turn brown to black and might also be associated with hormonal influence of ethylene. The disorder is aggravated when plant pathogens take advantage of the accelerated tissue damage. In addition, desiccation conditions during storage induce large visible affected tip burn in lettuce, whereas internal browning is detected until harvest in Brussels sprouts and cabbages.

BITTER PIT

Bitter pit (Fig. 15.12) is a disorder affecting the appearance of apples. The disorder consists of circular depressions of dark skin color affecting the postharvest quality of fruit. The disorder has been related to a localized calcium deficiency during the stages of cell division and elongation occurring during a period of 4–6 weeks after anthesis. Mineral imbalance in this stage might produce a decrement in calcium levels and the consequent increment of potassium and magnesium concentration, thus affecting cell membrane permeability and progressive cell death. Bitter pit symptoms appear more frequently at the end of the fruit calyx and are seasonally associated with dry summers. The varietal sensibility is a main factor influencing the disorder; that is the cultivars Granny Smith, Gala, Golden Delicious, and Honeycrisp might present the symptoms even before harvest. Other closely related factors are excessive nitrogen nutrition, high salinity, poor pollination, light crop load, and elevated positions of fruit on the trees. Other disorders occurring in apples during storage are Jonathan spot, internal breakdown, and storage scalds.

BLOSSOM-END ROT

Blossom-end rot is one of the disorders causing important economic losses in crops such as tomatoes and watermelons, especially in susceptible varieties. It constitutes a severe disorder affecting fruit quality and is associated with the incomplete absorption and distribution of calcium during stages of high mineral demand. The divalent cation could be compromised due to a lack of intermolecular binding to pectins from the cell wall, thus reducing the capacity of cell strength mediated by "egg box"-type pectins. "End rot" refers to the distinctive symptom of rotting on the bottom of immature or ripening fruit. The lesion starts as a limited depressed lesion that becomes enlarged and sunken as an oxidized dark spot. Prevention during the preharvest management of nutrition is a unique control strategy to prevent blossom-end rot. Factors related to the disorder severity are similar to previously discussed for bitter pit.

BLACKHEART

Blackheart is a disorder present in celery; it shares symptoms with tipburn. It is recognized by the necrotic development in young leaves at the tip and progressive brown-to-black necrosis to the rest of the leaf. The incidence of blackheart symptoms is associated with calcium translocation to young actively growing tissues; applications of foliar calcium in older leaves will not control the disorder. Some control might be successful by spraying calcium as chloride or nitrate salts, although some new calcium-chelated presentations might improve the mineral absorption and translocation.

15.3.2 Mineral Excess

Imbalances due to the improper management of nitrogen are explained by its central role in protein conformation. Some negatively affecting disorders are brown checking, altered flavors in celery, and hollow stems in broccoli. Tomatoes show negative impacts by nitrogen excess, such as the reduction of sugar content, lower acidity, reduced volatile production, and variation in defense mechanisms to herbivores, thus affecting fruit quality and infestation by insect pests. Phosphorus and potassium are other minerals affecting chemical properties of fruit when found in high contents. High levels of phosphorus and potassium have been known to affect flavor. Likely phosphorus as an activator of synthesis and energy flow supports the sugar accumulation and the dominance of sweetness over organic acid concentration. Access of potassium induces the accumulation of vitamin C and other organic acids.

15.4 PHYSIOLOGICAL DISORDERS RELATED TO GASES

Atmosphere modifications and control, which commonly involve low levels of oxygen and high levels of carbon dioxide, are frequently used during the storage, transport, and packaging of some horticultural commodities (see Chapters 11, 13, and 18 in this book on packaging, controlled atmosphere storage, and transport). Fresh horticultural commodities vary in their tolerance to different levels of oxygen and carbon dioxide. Levels lower than the tolerated oxygen and higher than the tolerated carbon dioxide levels for sufficient periods of time cause injury (Figs. 15.14–15.16) and losses in fresh horticultural commodities.

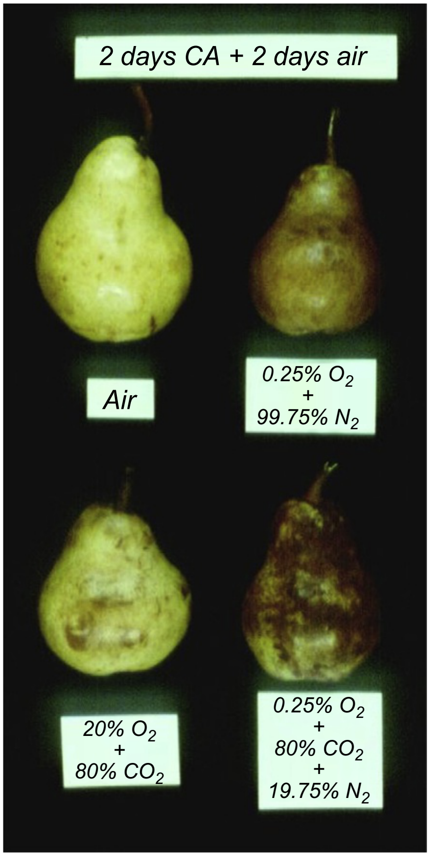

FIG. 15.14 External injury on pear fruit exposed to very low oxygen and very high carbon dioxide atmospheres.

15.4.1 Low-Oxygen Disorders

The external symptoms of low oxygen injury consist of brownish areas on the skin, ranging from definite small patches to large areas of the fruit surface. These symptoms are similar to those described for scald. The internal symptoms (Figs. 15.14 and 15.15) consist of brownish corky sections with occasional cavities inside the fruit. External and internal symptoms are sometimes contiguous. The browning intensity may depend on variety characteristics; for example, McIntosh apples show less intense brown than Delicious. Rotting may occur on the sites of external injury. Additional symptoms sometimes include bleaching or scalding of the skin, purpling of the skin blushed areas, and fermentative odors and flavors. Additional risk of injury may be induced by late harvest, by establishing the low-oxygen atmosphere 1 week of fruit harvesting, by slow oxygen reduction of the atmosphere, or by slow cooling of the commodity. Additionally a higher incidence of low-oxygen injury may be induced by adding carbon dioxide to the low-oxygen atmosphere. Sensitivity and tolerance to low-oxygen atmospheres vary among species and cultivars of the same species. For examples, citrus fruits are very sensitive to low oxygen injury. Oranges stored

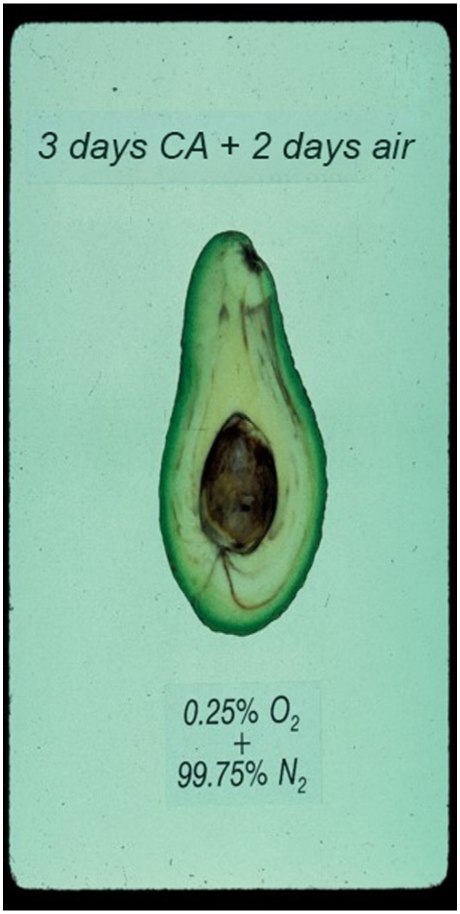

FIG. 15.15 Low-oxygen injury on the pulp of avocado fruit.

for 12 weeks at 0°C in an atmosphere of 0% oxygen show scald-like symptoms on the peel, and oxygen levels below 5% can result in off-flavors in the juice caused by ethanol and acetaldehyde accumulation. Among varieties, observations indicate that McIntosh apples may be the most sensitive to low-oxygen injury and Delicious is moderately sensitive, whereas Northern Spy and Empire apples are relatively tolerant. The risk of low-oxygen injury can be reduced by selecting recently harvested fruit for storage in controlled atmospheres, avoiding delays in cooling, promptly implementing the atmosphere, and minimizing variation in the levels of gases of the atmosphere. If the low-oxygen injury has started but is not as severe, then aeration may recuperate the tissue and eliminate some of the off-flavors and off-odors.

15.4.2 High-Oxygen Disorders

Very high, super-atmospheric oxygen (i.e., higher than the 20–21 kPa commonly found in normal air) can cause injury to some commodities. Apples of the cultivar Bramley's Seedling

FIG. 15.16 High carbon dioxide injury on the pulp of avocado fruit.

stored for 4 months at 4°C in 100 kPa O_2 exhibit browning of skin and flesh and mealy flesh. Granny Smith apples accumulate high ethanol concentrations and show a bronzed coloration when stored at 100 kPa O_2 for >3 months. Gala and Granny Smith apples exposed to 100 kPa O_2 develop extensive injury similar to that presented under atmospheres of low (1.0 kPa) O_2. Mature green tomatoes show dark brown spots on skin when exposed longer than 5 days to 80 or 100 kPa O_2; the severity depends on exposure time. An additional effect of the super-atmospheric oxygen levels is the intensification of disorders related to ethylene on some vegetables. For example the ethylene-stimulated biosynthesis of isocoumarin in carrots stored in air containing 500 µL/L ethylene is increased 5-fold when stored in 100 kPa O_2 containing the same level of ethylene. Additionally, ethylene production and ethylene-induced russet spotting disorder on lettuce are magnified by high-oxygen atmospheres.

15.4.3 High Carbon Dioxide Disorders

This injury (Figs. 15.14 and 15.16) is often the result of the exposure to atmospheres containing CO_2 levels above those tolerated by the produce. The injury can be present in produce that is stored, transported, or packed in intentionally developed modified or controlled atmosphere systems, as well as in produce packed in gas-tight containers. The severity of carbon dioxide injury depends upon several factors, such as CO_2 concentration, duration, O_2 concentration, storage temperature, cultivar, and fruit ripeness stage. Sensitivity/tolerance to carbon dioxide also vary among species and cultivars. For example, lettuce is very sensitive, while most berries are very tolerant to carbon dioxide. Among sensitive apple cultivars to carbon dioxide injury are Cortland, Cox's Orange Pippin, Golden Delicious, Granny Smith, Jonathan, McIntosh, Northern Spy, and Rome Beauty. A highly sensitive cultivar is Newton Wonder, which can be internally injured by 3 kPa CO_2. On the other hand, Worcester Pearmain is a tolerant cultivar able to support CO_2 levels as high as 13 kPa. The differences in sensitivity among different fruits and cultivars are probably due to anatomical, morphological, or biochemical causes and differences. For instance, some of the anatomical and morphological differences that affect carbon dioxide tolerance and injury include the size of intercellular spaces and the amount of lenticels per unit of area on skin. CO_2 levels higher than 20 kPa are generally harmful for most fresh horticultural commodities. These CO_2 levels can lead to tissue breakdown and acetaldehyde and ethanol accumulation, as well as undesirable off-odors. A proper knowledge of postharvest produce procedures (e.g., harvesting, handling, storage, packaging, and transportation) is required to minimize carbon dioxide injury during modified and controlled atmosphere storage, transport, and packaging.

15.4.4 Ethylene Disorders

Ethylene may cause physiological disorders in fruits and vegetables. Certain disorders, such as bitterness caused by the accumulation of isocoumarin in carrots, russet spotting in lettuce, toughness in asparagus spears, uneven degreening in citrus, and induced yellowing in fruits and vegetables (Figs. 15.17 and 15.18), are commonly observed during the handling of fresh horticultural commodities. Ethylene-caused disorders commonly result from exposure to very low levels of ethylene. In the case of carrot root discs, exogenously applied ethylene levels above 0.3 ppm have shown to be sufficient to induce the formation of isocoumarin. Isocoumarin content of 20 mg/100 fw in carrots can be detected by consumers. The amount of isocoumarin can be reduced by carbon dioxide due to its property as an inhibitor of ethylene action. Exposure of lettuce to ethylene induces russet spotting, which is characterized by small reddish-brown spots on the midribs of lettuce leaves. Russet spotting develops with ethylene levels as low as 1 ppm in lettuce maintained at 5°C.

Ethylene-induced disorders, such as bitterness by isocoumarin in carrots, russet spotting in lettuce, ethylene-induced yellowing in broccoli and several other commodities, among several other disorders, can be prevented or reduced by avoiding exposure to ethylene and by avoiding stresses that induce ethylene synthesis, such as tissue wounding, diseases, and storage at inappropriate temperatures. 1-Methylcyclopropene (1-MCP) is an inhibitor of ethylene

FIG. 15.17 Overmature green beans.

FIG. 15.18 Overmature zucchini due to several possible reasons, including water loss and senescence.

FIG. 15.19 Superficial scald on apples.

action whose applications have shown to prevent some ethylene-induced disorders such as yellowing in broccoli.

15.5 OTHER DISORDERS

Several other physiological disorders can be induced in fresh horticultural commodities, such as those associated with long-term storage, including superficial scald (Fig. 15.19) and water core in apples (Fig. 15.10). Superficial scald is caused by the oxidation of alpha-farnesene and can be avoided by the application of antioxidants, such as diphenylamine and ethoxyquin.

15.6 COMMON PHYSIOLOGICAL DISORDERS IN SELECTED FRUITS AND VEGETABLES AND POSSIBLE CONTROLS

15.6.1 Tomato Chilling Injury and Its Control

Tomato CI is shown as surface pitting, disease susceptibility, inhibition of ripening, uneven color development, increased respiration following chilling, and augmented ion leakage. Storage of mature green tomatoes at temperatures below 14°C for longer than 2 weeks or at 5°C for longer than 1 week are sufficient to develop chilling injury. Ideal control of CI is to always maintain the fruit at optimum temperature. However, treatments with 1–2 mM salicylic acid applied on mature green tomatoes alleviate CI. This chemical treatment provokes increased proline levels, reduced electrolyte leakage, decreased malondialdehyde content, and an inhibition in phospholipase D and lipoxygenase activities during cold storage. It is believed that the inhibitory effect on the activity of these enzymes might be part of a mechanism by which the oxidation damage is decreased and the cellular membrane integrity is enhanced, resulting in CI amelioration. On the other hand aphysical treatment known as "heat-shock treatments," such as the immersion of mature green tomatoes in water at 40°C for 7 min, can result in a reduction in CI symptoms after being stored at low (2.5°C) temperatures for 14 days. It is believed that heat-shock treatments induce tolerance to CI that seem to be associated with the maintenance of the stability in the levels of certain metabolites, such as arabinose, fructose–phosphate, valine, and shikimic acid.

15.6.2 Mango Chilling Injury and Its Control

CI in mangoes is characterized by dark scald-like discolorations around lenticels on the peel, which are extended to produce more or less circular lesions. Pitting is also observed on the peel, whereas discoloration and off-flavor development are commonly present in the pulp. In order to control CI and contrary to the heat-shock treatment previously mentioned, cold-shock treatment, which consists of exposing the fruit to a cold temperature (0–4°C) for few hours (4–12 h), followed by an exposure to moderate temperatures (20°C) for a brief time (20h), before the definitive storage at low temperatures have been investigated with some varying results. The CI index of mango fruit (Mangifera indica L. cv. Wacheng) cold shocked at 0°C for 4 h and transferred to 20°C for 20 h is usually about 60% lower than that of control fruit directly stored at 2°C. Ion leakage and the malondialdehyde contents diminish, whereas glutathione and phenolic compounds increase in the cold-shocked fruit in comparison to the control fruit. The activities of the enzymes catalase and ascorbate peroxidase are markedly enhanced in the treated fruit during the storage. These cold-shock treatments appear to be a possible alternative approach to reduce chilling injury in mango fruit.

15.7 CONCLUSIONS

Physiological disorders in fresh horticultural commodities are very diverse and can result in major qualitative and quantitative losses, especially in the case of CI. The avoidance of physiological disorders of different causes mainly requires effective pre- and postharvest handling rather than applying control treatments after harvest. The proper applications of the knowledge about plant mineral nutrition, the atmosphere gas composition tolerated by the commodity during, and the safe temperature of storage and transport may avoid the development of physiological disorders. However, controlling CI in sensitive commodities applying a proper treatment(s) could result in shelf life extension for the commodities to reach the markets. These chemical and/or physical alternatives are thought to strengthen both the cell membrane integrity and the cellular antioxidative system and therefore might contribute to control certain disorders, such as CI.

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