Controlled atmosphere (CA) and modified atmosphere (MA) are most widely used for the commercial storage and transportation of apples and pears. After it was first described in the U.K. in the 1920s and actively researched in several countries in the 1930s and 1940s, the commercial use of CA storage for apples rapidly expanded in the 1950s and has subsequently been adopted worldwide. Since its initial commercialization in the 1950s, several improvements in CA technology have been made. These include rapid CA systems, which allow atmosphere set-points to be reached within 1 or 2 days; use of low oxygen concentrations (0.7–1.5 kPa) that can be accurately monitored and controlled; ethylene-free CA, programmed (or stepwise) CA, and dynamic CA where levels of \(O_2\) and \(CO_2\) are modified as needed, based on monitoring specific attributes of produce quality, such as ethanol concentration and chlorophyll fluorescence. MA packaging of pome fruits includes
pallet covers, consumer bagging, and most commonly for packaging fresh-cut apples and pears. A generally used MA approach for intact pome fruits is the application of edible coatings (waxing) in the United States and many other countries.

1-Methylcyclopropene (1-MCP), an ethylene inhibitor, was approved by U.S. EPA in 2002 and produced by AgroFresh Inc. (Springhouse, PA) with the commercial trademark of SmartFresh™. The use of 1-MCP in combination with CA can further improve storability of fruits and this has led to changes in CA storage management, particularly for apples.

12.1 Apple

12.1.1 Maturity

In general, an apple fruit harvested for CA storage must be less mature than fruit destined for earlier marketing after harvest. Overmature fruit have poor storability, and short storage life; fruits lose firmness and acidity quickly, and certain physiological disorders become more obvious, e.g., senescent breakdown and watercore. However, fruit harvested at an immature stage have poor eating quality upon ripening with little or no typical apple/fruit flavor and taste, and lack of juiciness and crispness. Most cultivars harvested at an immature stage can be more susceptible to physiological disorders such as bitter pit and superficial scald. The most widely used maturity indicators for apples include flesh firmness, starch content, sugar content (soluble solids content (SSC); expressed as % or °Brix), fruit color, and internal ethylene concentration. The following attributes are also used as supplemental maturity indicators: titratable acidity content, days from full bloom, and temperature accumulation. Fruit harvested at optimum maturity and handled properly have good storability and good eating quality. Although the benefit from CA storage is clear for fruit quality maintenance, in commercial practice, only fruits, which will be stored for 3 months or longer, are stored in CA because of cost. ‘Gala’ apples sometimes are stored in CA for less than 3 months due to the poor storability of that cultivar and its high relative financial return. A proper harvest prediction program ensures that representative fruit are tested for maturity within each orchard and each block by experienced personnel. The testing should begin in the orchard on a regular basis at least 2 to 3 weeks prior to the anticipated harvest date.

A “harvest window” for many cultivars is only a few days and an even narrower period is acceptable for long term CA storage. It has been suggested that ethylene production or internal ethylene concentration (IEC) should be a major determinant of harvest decisions (Lau, 1985). However, because the relationship between ethylene production and optimum harvest dates may not always be high (Watkins et al., 2004) and because ethylene measurements require expensive equipment, flesh firmness, starch iodine tests and surface color are most commonly used as maturity indices in commercial practice.

Production areas, yearly climate differences, tree age and vigor, and field practices influence maturity. Therefore, maturity estimation is usually based on a combination of regional maturity indicators, advice of local extension personnel, and experience of packinghouse technical personnel. Field production practices can complicate the maturity determination. For example, the background color of many apple cultivars is strongly influenced by nitrogen fertilization levels. Another example is that ‘Fuji’ apples growing on light crop trees mature earlier than well-cropped trees by as much as 10 days (Kupferman, 1997). Heavily cropped ‘Honeycrisp’ trees produce poorly colored, low-quality fruit (Embree et al., 2007). Thus fruit color is not a good maturity indicator.
The Streif index, a maturity determination method named after its developer, Dr. Josef Streif from Germany, appears to be less sensitive to year and location variations, giving it good potential for regional utilization (Streif, 1996). It is calculated with the formula: firmness / (soluble solids × starch index).

There are three features which make this approach appealing: its simplicity; all three measurements are accepted already as important individual measurements; these measurements are rapid, inexpensive and easily done by any orchard manager. The application of the Streif index has been studied on various popular European cultivars grown in different regions of Europe and other countries (Prange and DeLong, 1998).

ReTain™ (Valent BioScience, Libertyville, Illinois) is the commercial trademark for the plant growth regulator aminoethoxyvinylglycine (AVG), which blocks the production of ethylene (Byers, 1997; Greene, 2005). When ReTain is applied to apples, several ripening processes are slowed, including preharvest fruit drop, fruit flesh softening, starch disappearance, and red color formation (Byers, 1997; Greene, 2005). Fruit treated with ReTain can be picked during the normal harvest period for enhanced retention of firmness in regular cold or CA storage, or harvest may be delayed without significantly sacrificing fruit firmness, allowing the fruit to continue to grow and develop red color for an extended time. But one of the greatest benefits of using ReTain is reduction in preharvest fruit drop, often by as much as 30% for ‘McIntosh’ (Greene, 2005).

Fruits, which are to be treated with 1-MCP after harvest, can be harvested when they are more mature than fruits that will not be treated. However, fruit must be at the preclimacteric stage. The expected result is that these later-harvested fruit have a better eating quality without loss of storability. By harvesting more mature fruit, it may have time to grow larger in size and improve the pack-out returns. See Section 12.1.3 for detailed information about the interaction of 1-MCP and CA.

12.1.2 CA Regimes

12.1.2.1 Temperature Control in CA Room

CA rooms should be precooled to the desired set-point before product loading begins. Most, but not all, cultivars will retain fruit quality better if rapidly cooled to 0°C–1°C within 3 days after harvest (Table 12.1). Delayed cooling is associated with shortened storage life, flesh softening, increased physiological disorders, and storage disease. However, there are some cultivars that do not respond well to rapid cooling. A new cultivar, ‘Honeycrisp,’ develops several disorders unless cooling is delayed for at least 7 days at 20°C (Delong et al., 2004b, 2006). Some cultivars are sensitive to low temperature, which causes chilling injury. Depending on the cultivar and the growing region, recommended storage temperatures can be as high as 4°C (Kupferman, 2003). ‘Braeburn’ and ‘Fuji’ require a stepwise cooling: fruit are loaded at 2°C–3°C and gradually cooled to 1°C with 2–3 weeks. ‘Pink Lady’ requires cooling down slowly to 0.5°C–1°C over a 5–7-day period. Delayed cooling can reduce internal browning of ‘Delicious’ fruits that have severe watercore at harvest. Watercore is a physiological disorder of apple fruit characterized by water-soaked tissue around the vascular bundles or core area due to the spaces between cells becoming filled with sorbitol-rich fluid instead of air (Marlow and Loescher, 1984). Recovery from watercore can occur if the fruits are handled gently, i.e., with gradual or delayed cooling.

Other factors can influence response of fruit to low temperature. When decreasing temperature from 1°C to 0°C, maintenance of the RH >90% becomes much more difficult, and therefore this last degree of cooling leads to an increased risk of fruit dehydration. For ‘McIntosh’ and other low-temperature sensitive cultivars, a temperature below 3°C may cause injury during long-term storage, but the risk is low for short-term storage of 2 or 3 months.
### TABLE 12.1

Storage Characteristics of Several Apple Varieties in Air and CA

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Temperature (°C)</th>
<th>Cooling Rate(^a)</th>
<th>Air Storage Life (months)</th>
<th>CO(_2) (kPa)</th>
<th>O(_2) (kPa)</th>
<th>Storage Life (months)</th>
<th>Rapid CA Availability(^b)</th>
<th>CO(_2) Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Braeburn</td>
<td>1</td>
<td>Stepwise</td>
<td>3-4</td>
<td>0.5</td>
<td>1.5-2</td>
<td>8-10</td>
<td>Slow</td>
<td>Sensitive</td>
</tr>
<tr>
<td>Delicious</td>
<td>0</td>
<td>Rapid</td>
<td>3</td>
<td>2</td>
<td>0.7-2</td>
<td>12</td>
<td>Rapid to moderate(^b)</td>
<td>Slow</td>
</tr>
<tr>
<td>Empire</td>
<td>2</td>
<td>Slow</td>
<td>2-3</td>
<td>2-3</td>
<td>2</td>
<td>5-10</td>
<td>Slow</td>
<td>Sensitive</td>
</tr>
<tr>
<td>Fuji</td>
<td>0-1</td>
<td>Stepwise</td>
<td>4</td>
<td>0.5</td>
<td>1.5-2</td>
<td>12</td>
<td>Slow</td>
<td>Sensitive</td>
</tr>
<tr>
<td>Gala</td>
<td>0-1</td>
<td>Rapid</td>
<td>2-3</td>
<td>2-3</td>
<td>1-2</td>
<td>5-6</td>
<td>Rapid</td>
<td>Slow</td>
</tr>
<tr>
<td>Golden Delicious</td>
<td>0-1</td>
<td>Rapid</td>
<td>3-4</td>
<td>2-3</td>
<td>1-2</td>
<td>8-10</td>
<td>Rapid</td>
<td>Slow</td>
</tr>
<tr>
<td>Granny Smith</td>
<td>1</td>
<td>Rapid</td>
<td>3-4</td>
<td>0.5</td>
<td>1.5-2</td>
<td>10-11</td>
<td>Slow</td>
<td>Sensitive</td>
</tr>
<tr>
<td>Jonagold</td>
<td>0</td>
<td>Rapid</td>
<td>2</td>
<td>2-3</td>
<td>1-1.5</td>
<td>5-7</td>
<td>Rapid</td>
<td>Slow</td>
</tr>
<tr>
<td>Pink Lady</td>
<td>1</td>
<td>Slow</td>
<td>3-4</td>
<td>1</td>
<td>2</td>
<td>9</td>
<td>Slow</td>
<td>Slow</td>
</tr>
</tbody>
</table>


\(^a\) Cooling rate and rapid CA availability (O\(_2\) pulldown rates): Rapid = within 3 days; Slow = 5-7 days; Stepwise = 2°C-3°C during loading, 2°C at sealing, and 1°C after 2-3 weeks of CA establishment.

\(^b\) Fruit for long-term CA are recommended to use rapid CA, but water-cored fruit should be stored at high oxygen (2-2.5 kPa) to prevent internal breakdown.
12.1.2.2 Control of Gas Components

After loading fruit, the temperature is reduced to below 10°C, hydrated lime may be placed in the room to remove extra CO₂ and then CA rooms are sealed. After the room temperature is subsequently reduced to below 5°C, nitrogen is injected to pull down the oxygen levels. Until the mid-1970s, 8-10 days were often required to load a CA room and a further 15-20 days were needed for fruit respiration to lower O₂ to 2.5-3 kPa. New technologies, which were developed in the 1980s, such as pressure swing adsorption (PSA) and selective gas-permeable membranes for separating nitrogen, oxygen, carbon dioxide, make it possible to pull down O₂ to 1 kPa in 1 or 2 days. Adoption of rapid and low O₂ CA has significantly improved the storage and marketing quality of fruit.

The recommended gas conditions vary among cultivars, growing regions, and years. General recommendations include 1-2 kPa O₂ and 0.5-2 kPa CO₂ (Kupferman, 2003; Watkins et al., 2004).

The recommendations have been changed over time due to research progress in plant physiology and improvements in gas control technology. Suggested CA storage oxygen levels for 'Delicious' apples in the U.S. Pacific Northwest was 2-3 kPa O₂ until the early 1980s. Lau (1983) and Chen et al. (1985) reported that it looked as though 1 kPa is adequate. British Columbia-produced 'Delicious' can be stored safely at 0.7 kPa O₂ (Lau, 1997), but the same cultivar from other growing regions may show injury at such a low oxygen (Lau et al., 1998). Recently, a chlorophyll fluorescence-based low-O₂ CA system, so-called "dynamic CA" has been developed, which can indicate the lowest acceptable oxygen. Under this system, low oxygen problems can be potentially avoided (Prange et al., 2003).

Table 12.1 shows current recommendations for the major U.S. cultivars. Kupferman (2003) has produced a much longer list including 33 cultivars from over 11 growing regions worldwide.

Low ethylene CA storage (<1 ppm) was evaluated as a method to enhance storage performance by slowing softening and reducing superficial scald (Blanpied, 1990). However, Lau (1999) concluded ethylene scrubbing offers no firmness and scald benefits to 'Golden Delicious,' 'Delicious,' and 'Spartan' apples in low-oxygen CA storage. Therefore, there has been a limited commercial use of this approach.

In addition to slowing ethylene production, respiration, ripening, and senescence of apple fruits and decreasing decay incidence, CA also plays an important role in controlling superficial scald, a severe postharvest physiological disorder on some apple cultivars. In British Columbia, Canada, 0.7 kPa O₂ storage is used as a substitute for DPA treatment, the commonly used antioxidant to control scald (Lau, 1997; DeLong et al., 2004a, 2007). A stress level of low O₂ at 0.25-0.5 kPa for up to 2 weeks, before regular CA storage, controls superficial scald of 'Granny Smith,' 'Delicious,' and 'Law Rome' (Little et al., 1982; Wang and Dilley, 2000; Zanella, 2003). Although it has been subjected to commercial trials, the extent of commercial adoption of this practice is not known.

12.1.2.3 Dynamic CA

Apples in storage are living, and respiration and other metabolic processes are dynamic. However, most recommendations for certain cultivars are static from the beginning to the end of storage. Therefore, it is expected that the recommended CA conditions are not the best fit to the fruit at all points during the storage period. Dynamic CA has been developed to maintain CA conditions in storage over time to best fit the needs of living fruit at any point in time during the storage. A dynamic control of CA through monitoring ethanol production has been proposed (Veltman et al., 2003) but not yet commercialized. Currently commercialized dynamic CA technology is based on a continual measurement
### TABLE 12.2

Low-O\textsubscript{2} Thresholds Determined for Each Cultivar by HarvestWatch and the Subsequent Range of O\textsubscript{2} Levels Employed in Dynamic CA Storage

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Low-O\textsubscript{2} Threshold (kPa)</th>
<th>O\textsubscript{2} Setting for Each Cultivar (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortland</td>
<td>0.5</td>
<td>0.6-0.8*</td>
</tr>
<tr>
<td>Delicious</td>
<td>0.4</td>
<td>0.5-0.8</td>
</tr>
<tr>
<td>Golden Delicious</td>
<td>0.5</td>
<td>0.5-0.8</td>
</tr>
<tr>
<td>Honeycrisp</td>
<td>0.4</td>
<td>0.5-0.8</td>
</tr>
<tr>
<td>Jonagold</td>
<td>0.5</td>
<td>0.5-0.8</td>
</tr>
<tr>
<td>McIntosh</td>
<td>0.8</td>
<td>0.9-1.0</td>
</tr>
</tbody>
</table>


* O\textsubscript{2} levels reflect the ideal setting (0.1-0.2 kPa above the detected low-O\textsubscript{2} threshold value) and the system variation encountered during the storage period.

...of chlorophyll fluorescence; i.e., the HarvestWatch\textsuperscript{TM} system designed by Satlantic (Nova Scotia, Canada).

DeEll et al. (1995) first reported that chlorophyll fluorescence was affected by low oxygen and high CO\textsubscript{2} in CA storage of ‘McIntosh’ apples. DeEll et al. (1998) and Prange et al. (2002, 2003) confirmed the phenomenon. DeLong et al. (2004a) reported that with this chlorophyll fluorescence technology, the lowest acceptable O\textsubscript{2} concentration in CA is much lower than the recommendations in Table 12.1. The range is 0.4-0.8 kPa (Table 12.2) and closer to the theoretical lower limit for aerobic respiration. Using HarvestWatch to dynamically control O\textsubscript{2} concentrations just above the O\textsubscript{2} threshold concentrations in CA-stored apples results in improved quality retention and eliminates the occurrence of superficial scald in susceptible apple cultivars (DeLong et al., 2004a; Zanella et al., 2005).

The principle underlying chlorophyll fluorescence analysis is relatively straightforward. Light energy absorbed by chlorophyll molecules in an apple can undergo one of three fates: it can be used to drive photosynthesis (photochemistry), excess energy can be dissipated as heat, or it can be re-emitted as light-chlorophyll fluorescence. These three processes occur in competition, such that any increase in the efficiency of one will result in a decrease in the yield of the other two. Hence, by measuring the yield of chlorophyll fluorescence, information about changes in the efficiency of photochemistry, and heat dissipation can be gained (Maxwell and Johnson, 2000). There is a consistent emission spike of the chlorophyll fluorescence parameter \( F_{o} \), which occurs when fruit is exposed to oxygen levels at the anaerobic threshold in CA-stored fruits and vegetables (Figure 12.1, Prange et al., 2003, 2005a). The reason for the change in chlorophyll fluorescence due to low O\textsubscript{2} and high CO\textsubscript{2} has been proposed as an occurrence of cytoplasmic acidosis (Prange et al., 2005a,b). Gout et al. (2001) have shown that as anoxia is imposed, cytoplasmic pH drops (acidosis), and is correlated with the hydrolysis of adenosine triphosphate (ATP) and other nucleoside triphosphate (NTPs), which generate phosphoric acid, e.g., \( \text{ATP} + \text{H}_2\text{O} \rightarrow \text{ADP} + \text{H}_3\text{PO}_4 \). After returning the cells to normal air, the cytoplasmic pH increases; however, both the vacuolar and extracellular pH decreases. This suggests that cytoplasmic acidosis is reduced by transport of H\textsuperscript{+} out of the cytoplasm into the vacuole and cell wall (Gout et al., 2001).

The needs of “organic” apples are increasing, and it has been a challenge to store apples for an extended time without 1-MCP and other chemicals. Dynamic CA increases technology options for the apple industry, especially as a promising tool for the “organic” apple industry (DeLong et al., 2007).
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-5.0

0	 24	 48	 72	 96

Pome Fruits

O2

Fₐ

Fₐ (ambient air)

Time (h)

FIGURE 12.1
An example of the Fₐ fluorescence signal detected in Summerland McIntosh apples held at 20°C in air (open circle) and in a progressively diminished oxygen environment (dark circle). The spike in Fₐ begins as the chamber oxygen levels fall below 1 kPa at 72 h and continues upward until the oxygen concentration is increased at 84 h. (Reprinted from Prange, R.K., DeLong, J.M., and Harrison, P.A., J. Am. Soc. Hort. Sci. 128, 603, 2003.)

12.1.3 1-MCP and CA

In recent years, a very effective agent, 1-MCP, for blocking the ethylene receptor has been widely used in the apple industry for extending storage life (Watkins, 2006; Mattheis, 2008). 1-MCP is an analogue of ethylene, which occupies ethylene receptors such that ethylene cannot bind and elicit action. The affinity of 1-MCP for the receptor is approximately 10 times greater than the affinity of ethylene (Sisler and Serek, 1997). Compared with ethylene, 1-MCP is active at much lower concentrations. 1-MCP also influences ethylene biosynthesis in some species through feedback inhibition. Although Harvesta SM (AgroFresh, Springhouse, Pennsylvania), a preharvest sprayable application of 1-MCP is being researched and may be added to the label in the United States, we will only discuss SmartFresh, which is applied after harvest, in this chapter.

Generally, apples treated with SmartFresh are stored in CA for long-term storage. Research shows that the combination of 1-MCP and CA is more effective in maintaining fruit quality than when either 1-MCP-treated apples are stored in air or non-1-MCP-treated fruit are stored in CA. Due to the interaction between CA and 1-MCP, SmartFresh has brought an additional dimension to storage management decisions, which must respect 1-MCP interaction with cultivar, harvest maturity, storage temperature, and atmosphere, and the entire storage strategy.

SmartFresh application has increased the need for accurate maturity information, as optimizing results with SmartFresh technology depends on firmness levels of incoming fruit. Current SmartFresh apple use recommendations are mean flesh firmness 76 N for ‘Cripps Pink,’ 71 N for ‘Delicious,’ ‘Fuji,’ ‘Gala,’ and ‘Granny Smith,’ and 67 N for ‘Golden Delicious’ and ‘Jonagold’ (AgroFresh Inc., 2007).

Some storage operators have altered CA conditions based on the retarded rates of fruit ripening after SmartFresh treatment. The use of higher O₂ and higher temperature has increased due to the lower risk of low O₂ and/or low temperature injuries, and also to help
reduce operational expenses and energy use (Mattheis, 2008). Another change in CA operations following the availability and use of SmartFresh is opening and resealing CA rooms to remove individual orchard lots. Because 1-MCP-treated fruit are less sensitive to short interruptions of CA and/or low-temperature storage conditions, some warehouses have utilized this practice successfully to pack and market individual lots to optimize quality and/or fulfill market demands.

Without SmartFresh treatment, apples ripen faster after being removed from CA and/or low temperature storage. SmartFresh slows the ripening of fruit, thus allowing a longer marketing time (Fan et al., 1999; Bai et al., 2005; Watkins, 2006; Mattheis, 2008).

Some special attention should be paid when applying SmartFresh. For example, the presence of watercore may limit the use of SmartFresh as 1-MCP can delay the dissipation of watercore (Mattheis, 2008).

12.1.4 Modified Atmosphere Packaging

The use of polymeric films for packaging apples using pallet or bin covers, box polyliners, and consumer bagging or wrapping continues to increase. The marketability of fresh-cut apples has expanded rapidly, in part due to improvements in modified atmosphere packaging (MAP) technology. When fruit are sealed in a polymeric film, the gas composition inside the film will be modified by respiration of fruit to low O$_2$ and/or high CO$_2$. O$_2$ and CO$_2$ concentrations depend on respiration rate, product mass, gas permeability of film, film surface area, and film thickness.

Fruit retains a stable and low respiration rate in cold storage. However, at nonrefrigerated retail display or room temperature conditions, respiration rates generally are high and the onset of climacteric rise can dramatically increase the respiration rates over 10 times. As temperature increases, permeability of film also increases gradually. For instance, O$_2$ permeability through low-density polyethylene (LDPE) can increase by twofold from 0°C to 15°C (Moyls et al., 1998).

LDPE film is one of the most popular films in produce packaging. The oxygen transmission rate (OTR) of LDPE film is about 7000–7500 mL m$^{-2}$ 24 h$^{-1}$ and CO$_2$ transmission rate is usually two to six times greater than the OTR (Brody, 2005). New technologies are now allowing the manufacture of very high OTR (>15,000 mL m$^{-2}$ 24 h$^{-1}$) films for application to very high respiration rate commodities. Microperforated and microporous films are alternative approaches to providing high OTR. However, for perforated films, the diffusion to CO$_2$ is equal to that of O$_2$ (Brody, 2005). As a result, it is impossible to achieve low O$_2$ (1%–5%) without accumulating high CO$_2$ (15%–20%). Thus, these films are applicable only for those products that tolerate high CO$_2$. Regular perforated films, such as those with 2–10 mm diameter holes, usually cause a very limited atmosphere modification.

The range of steady-state O$_2$ and CO$_2$ levels in the packaging varies from 1 to 15 kPa and from 1 to 30 kPa, respectively (Ueda et al., 1993; Soliva-Fortuny et al., 2005; Rojas-Grad et al., 2007). Fresh-cut apples generally are handled under cold chain, allowing a low O$_2$ concentration to prevent fruit from browning and to reduce microbial growth if there is assurance that the product will not have a risk of exposure to warm temperature during distribution.

Recently, a side-chain polymer technology was developed that allows the film OTR to increase rapidly as temperature increases, thereby avoiding anaerobic conditions subsequent to loss of temperature control. These polymers also provide an adjustable CO$_2$/O$_2$ permeability ratio and a range of moisture vapor transmission rates (Zagory, 1997).

Accumulations of organic volatiles, such as alcohols, aldehydes, and jasmonates may have physiological and/or quality effects on fruits. Certain volatiles, such as hexanal, are of overall benefit, while others can lead to decline in quality and storability (e.g., ethanol and acetaldehyde) (Toivonen, 1997).
12.1.5 Edible Coatings

Coatings may be applied to apples just before marketing, to improve appearance to protect against water loss and shrinkage and modify the internal atmospheres that benefit quality by decreasing the rate of metabolism and senescence (Baldwin, 1994). Coatings can increase internal CO$_2$ and decrease O$_2$ partial pressures because they are gas barriers in a manner similar to MAP (Banks et al., 1993). There is a wide range of gas permeabilities for edible coatings; O$_2$ permeabilities ranged from 470 to 21,600, and CO$_2$ from 1700 to 175,000 mL mil m$^{-2}$ day$^{-1}$ atm$^{-1}$ at 50% RH for 19 commercial fruit coatings (Table 12.3, Hagenmaier and Shaw, 1992). The five coatings available for apples have O$_2$ permeabilities ranging from 470 to 4400, and CO$_2$ from 1700 to 16,000 mL mil m$^{-2}$ day$^{-1}$ atm$^{-1}$, respectively. Coatings applied to the surfaces of fruit and vegetables are commonly called waxes, whether or not any component in the product is actually a wax. The application of coatings to apples, prior to marketing, is standard practice in many countries, e.g., the United States. Freshly harvested apples have their own waxy coating, however, they are washed at the fruit packing sheds to remove dust and chemical residues and this washing removes about half of the original apple wax.

Major apple coatings are carnauba-based microemulsions, shellac-based solutions, or the mixture of the two coatings. Both carnauba and shellac have been used on a

<table>
<thead>
<tr>
<th>Major Ingredients</th>
<th>O$_2$ 50% RH</th>
<th>CO$_2$ 50% RH</th>
<th>C$_2$H$_4$ 50% RH</th>
<th>Water Vapor 92% RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waxes, natural and synthetic, and fatty acids</td>
<td>21,600</td>
<td>175,000</td>
<td>88,000</td>
<td>813,369</td>
</tr>
<tr>
<td>Polyethylene and shellac</td>
<td>11,200</td>
<td>37,000</td>
<td>17,000</td>
<td>4,256,000</td>
</tr>
<tr>
<td>Carnauba and fatty acids</td>
<td>10,300</td>
<td>49,000</td>
<td>14,000</td>
<td>13,240,889</td>
</tr>
<tr>
<td>Polyethylene-vinyl asetate copolymer (shrink-wrap film D955)$^a$</td>
<td>9,100</td>
<td>27,000</td>
<td>12,000</td>
<td>208,071</td>
</tr>
<tr>
<td>Carnauba and shellac$^b$</td>
<td>4,400</td>
<td>16,000</td>
<td>7,400</td>
<td>756,622</td>
</tr>
<tr>
<td>Shellac, carnauba and fatty acids$^b$</td>
<td>4,300</td>
<td>14,000</td>
<td>5,000</td>
<td>2,931,911</td>
</tr>
<tr>
<td>Carnauba, fatty acids and shellac$^b$</td>
<td>2,700</td>
<td>9,800</td>
<td>3,100</td>
<td>2,175,289</td>
</tr>
<tr>
<td>Coumarone-indene resin</td>
<td>2,600</td>
<td>7,600</td>
<td>940</td>
<td>1,418,667</td>
</tr>
<tr>
<td>Rosin and carnauba</td>
<td>2,500</td>
<td>7,200</td>
<td>930</td>
<td>2,837,333</td>
</tr>
<tr>
<td>Hydrocarbon resins and fatty acids</td>
<td>2,200</td>
<td>4,600</td>
<td>670</td>
<td>10,403,556</td>
</tr>
<tr>
<td>Rosin, oleic acid and shellac</td>
<td>2,000</td>
<td>3,600</td>
<td>450</td>
<td>4,256,000</td>
</tr>
<tr>
<td>Carnauba, morpholine and oleic acid$^c$</td>
<td>2,000</td>
<td>7,800</td>
<td>3,200</td>
<td>567,467</td>
</tr>
<tr>
<td>Shellac and rosin</td>
<td>1,700</td>
<td>3,800</td>
<td>610</td>
<td>3,404,800</td>
</tr>
<tr>
<td>Shellac and fatty acids</td>
<td>1,000</td>
<td>3,500</td>
<td>360</td>
<td>8,228,267</td>
</tr>
<tr>
<td>Shellac and rosin</td>
<td>1,000</td>
<td>2,600</td>
<td>270</td>
<td>13,524,622</td>
</tr>
<tr>
<td>Carnauba, shellac and rosin</td>
<td>1,000</td>
<td>2,800</td>
<td>400</td>
<td>9,457,778</td>
</tr>
<tr>
<td>Sucrose esters and carboxymethyl cellulose$^b$</td>
<td>800</td>
<td>4,500</td>
<td>1,980</td>
<td>8,228,267</td>
</tr>
<tr>
<td>Rosin, oleic acid and ammonia$^a$</td>
<td>780</td>
<td>2,200</td>
<td>170</td>
<td>28,373,333</td>
</tr>
<tr>
<td>Shellac and rosin</td>
<td>730</td>
<td>1,800</td>
<td>180</td>
<td>10,403,556</td>
</tr>
<tr>
<td>Shellac</td>
<td>640</td>
<td>1,900</td>
<td>170</td>
<td>5,485,511</td>
</tr>
<tr>
<td>Shellac, rosin and morpholine</td>
<td>550</td>
<td>1,700</td>
<td>140</td>
<td>11,349,333</td>
</tr>
<tr>
<td>Shellac$^b$</td>
<td>470</td>
<td>1,700</td>
<td>180</td>
<td>9,079,467</td>
</tr>
<tr>
<td>Shellac and morpholine$^a$</td>
<td>370</td>
<td>1,100</td>
<td>90</td>
<td>17,969,778</td>
</tr>
<tr>
<td>Modified maleic resin and morpholine$^a$</td>
<td>250</td>
<td>910</td>
<td>310</td>
<td>3,404,800</td>
</tr>
</tbody>
</table>


$^a$ Noncommercial coatings or shrink-wrap film.

$^b$ Coatings available for apples.
variety of foods for decades. Sucrose fatty acid ester coatings are approved for fruits, however, only a few apple packinghouses use them due to unsatisfactory gloss appeal that results.

‘Delicious’ apples have been a key apple cultivar in the development of apple coating formulations and technology, and because this cultivar is relatively tolerant to high gas barriers, the coatings developed have tended to emphasize improvement of visual gloss with little need for other effects on the fruit that might result from a high barrier to gas exchange (Baldwin, 1994). A shellac coating seems an excellent fit for dark red ‘Delicious’ apples, because it imparts high gloss, hides bruises and forms a MA condition that tends to preserve firmness and prolong shelf life in this cultivar (Bai et al., 2002a,b, 2003). Shellac has a problem with flaking (Hagenmaier and Shaw, 1992; Baldwin, 1994), which occurs when fruits are removed from cold storage to ambient air. Humidity in the air condenses on the fruit surface and melts part of the coating. After the condensation dries out, white spots remain on the surface. This whitening or chalky appearance limits marketability.

Carnauba use on apple coating has been increasing in the last decade. Carnauba wax does not discolor, but has less gloss than shellac. Bai et al. (2002a) reported that application of carnauba coatings results in less modification of the internal atmosphere in coated ‘Delicious’ apples compared with shellac, and is more effective in preventing weight loss.

It is well known that when fruit is separated by a barrier, such as a coating or packaging, from exchange of gases with the atmosphere there is the possibility for the respiration to become anaerobic, leading to the associated development of off-flavor. Coatings and packages developed for one type of fruit may not be suitable for another. Bai et al. (2002b, 2003) applied several experimental coatings, with a very wide range of gas permeabilities, to four apple cultivars (Figure 12.2). Shellac coating results in maximum fruit gloss, lowest internal O₂, highest CO₂, and least loss of flesh firmness for all of the cultivars. ‘Granny Smith’ with shellac has very low internal O₂ (<2 kPa), and freshly harvested ‘Braeburn’ has very high internal CO₂ (25 kPa). These excessive modifications of internal gas induces an abrupt rise of the respiratory quotient, prodigious accumulation of ethanol in both ‘Braeburn’ and ‘Granny Smith’, and flesh browning at the blossom end of ‘Braeburn’. In addition, the shellac coating results in an unusually high accumulation of ethanol in freshly harvested and 5-month-stored ‘Fuji’. Candelilla and carnauba–shellac coatings maintain better internal O₂ and CO₂ and better quality for ‘Fuji’, ‘Braeburn,’ and ‘Granny Smith,’ although even these coatings may present too much of a gas barrier for ‘Granny Smith.’ In general, the gas permeabilities of the coatings are useful as indicators of differences in coating barrier properties, but do not account for differences in pore blockage, which is expected to play a more important role in the gas exchange for the whole fruit (Bai et al., 2002b, 2003.). Candelilla wax coating, which has lower permeability than the carnauba–shellac coating, results in higher values in internal O₂ and lower CO₂. We can speculate that the carnauba–shellac coating has a greater tendency to block pores in the fruit skin, but have insufficient evidence to conclude that is the case (Bai et al., 2003).

‘Braeburn’ and ‘Granny Smith’ apples are sensitive to high CO₂ and also differ from ‘Delicious’ in the porosity of the peel and the structure of blossom- and stem-ends, and thus the same coating may result in a different modified internal atmospheres, and physiological reactions to a given internal gas composition may also differ. These considerations suggest it is appropriate to once again determine if coatings developed for ‘Delicious’ are optimum for other cultivars. There also seems to be a possibility that the trend in consumer preference for more ‘natural’ products might lead to less preference for high glossy coatings. In such cases, candelilla wax may be acceptable, which offers a moderate gas barrier and a natural gloss (Bai et al., 2003).
12.2 Pear

Pears are similar to apples regarding responses to environment temperature, humidity, and atmosphere. Thus many CA/MA storage technologies, which were developed for apples first, have been adapted for pear storage later. For instance, rapid cooling, rapid CA, and low O₂ CA have been adopted by the pear industry successfully, and dynamic CA is a potential tool for pears. On the other hand, pears are different from apples in many respects. The most significant is that pears generally are consumed after they are fully ripened with a juicy and buttery texture and distinct pear aroma and taste. Thus any storage and handling technologies, which may consequently disrupt the ripening ability, should be avoided. A good example is 1-MCP technology; postharvest application of 1-MCP has been shown in apples to be very effective at reducing superficial scald and extending storage life, however, in pear fruit, 1-MCP prevents the fruit from properly ripening.

12.2.1 Maturity

Pear fruits are capable of developing good dessert quality upon ripening only when they are harvested at proper maturity. Pear fruits harvested with improper maturity are more susceptible to physiological disorders and have a shorter storage life. Immature pear fruits are more susceptible to superficial scald, shriveling, and friction-generated discoloration. However,
TABLE 12.4
Storage Characteristics of Several Pear Varieties in Air and CA at −1.4°C to 0°C (Modified from Chen, 2004; Kader, 2007; Kupferman, 2003; Sugar, 2007.)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Harvest Flesh Firmness (N)</th>
<th>Air Storage Life (Months)</th>
<th>CO₂ (kPa)</th>
<th>O₂ (kPa)</th>
<th>Storage Life (Months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abate Fetel</td>
<td>58-67</td>
<td>3-4</td>
<td>0-1</td>
<td>1-2</td>
<td>4-6</td>
</tr>
<tr>
<td>Anjou</td>
<td>58-67</td>
<td>6-7</td>
<td>0-0.5</td>
<td>0.7-2</td>
<td>8-10</td>
</tr>
<tr>
<td>Bartlett</td>
<td>67-84</td>
<td>2-3</td>
<td>0-0.5</td>
<td>1-2</td>
<td>3-6</td>
</tr>
<tr>
<td>Bosc</td>
<td>62-71</td>
<td>4</td>
<td>0.5-1.5</td>
<td>1-2.5</td>
<td>5-7</td>
</tr>
<tr>
<td>Comice</td>
<td>49-58</td>
<td>4</td>
<td>0.5-4</td>
<td>1.5-4</td>
<td>5-6</td>
</tr>
<tr>
<td>Concorde</td>
<td>49-58</td>
<td>4-5</td>
<td>0-1</td>
<td>0.5-2</td>
<td>6-7</td>
</tr>
<tr>
<td>Conference</td>
<td>49-58</td>
<td>5-6</td>
<td>0.5-1.5</td>
<td>1-2.5</td>
<td>7-8</td>
</tr>
<tr>
<td>Forelle</td>
<td>58-67</td>
<td>4-5</td>
<td>0-1.5</td>
<td>1-2</td>
<td>6-7</td>
</tr>
<tr>
<td>Packham's Triumph</td>
<td>62-71</td>
<td>6</td>
<td>1.5-2.5</td>
<td>1.5-2</td>
<td>7-8</td>
</tr>
<tr>
<td>Winter Nelis</td>
<td>58-67</td>
<td>7-8</td>
<td>0-1</td>
<td>1-3</td>
<td>8-10</td>
</tr>
</tbody>
</table>


overmature fruits tend to have higher incidence of core breakdown, CO₂ injury, storage decay, and mealy texture upon ripening (Chen, 2004). Flesh firmness is a reliable maturity indicator (Chen, 2004), but sometimes a starch test is necessary, because in certain seasons, firmness will remain high for a time while the starch content changes (Kupferman, 2002). The measurement of pear flesh firmness uses the same penetrometer as used for apples: however, an 8 mm plunger is used for pears rather than the 11 mm plunger used for apples. Recommended ranges of firmness for harvesting different pear cultivars are as follows: ‘d’Anjou,’ 58 to 67 N; ‘Bartlett,’ 67 to 84 N, ‘Bosc,’ 62 to 71 N, and ‘Comice,’ 49 to 58 N (Table 12.4; Sugar, 2007).

12.2.2 CA Regime
12.2.2.1 Temperature

Pears are very sensitive to temperature. The storage life of ‘d’Anjou’ and ‘Bartlett’ pears is 35%-40% longer at −1°C than at 0°C (Porritt, 1964). Most pears in the Pacific Northwest are stored at −1°C with RH of 90%-94% (Hansen and Mellenthin, 1979). As long as the total soluble solids content in the core area is at least 11%, pears can be successfully stored at −1°C without freezing. Pears must be at final storage temperature before the oxygen is lowered. Many packing houses use thermocouples in the air and in fruit to determine temperatures at selected areas in the storage. Precise temperature control is needed to prevent freezing when pears are stored at these low temperatures. Rapid removal of field heat and prompt cooling of harvested pears are essential for long-term storage. During the pull-down period, room temperatures of −3.5°C to −2.0°C can be used but should be raised to −1°C as the fruit temperatures approach the target temperature (Hansen and Mellenthin, 1979). Delay in cooling shortens storage life. It has been recommended to rapidly cool down core temperature within 3 days of harvest for ‘d’Anjou’ pears (Swindeman, 2002).
Pears lose moisture rapidly; hence, it is advisable to hold the RH >90%. Polyethylene bin liners are effective in controlling moisture loss.

12.2.2.2 CA Regimes

CA storage has been used successfully to extend the storage life of pears and to maintain greater capacity for ripening. The optimum and safe CA atmosphere for commercial use is 1 to 2.5 kPa O₂ + 0 to 1.5 kPa CO₂ (Table 12.4). Use of short-term high CO₂ treatment improves keeping quality of ‘d’Anjou’ pears (Wang and Mellenthin, 1975). Treatment with 12% CO₂ for 2 weeks immediately after harvest has a beneficial effect on retention of ripening capacity. Keeping ‘d’Anjou’ pears in a low O₂ atmosphere (1.0 kPa) with <0.1 kPa CO₂ can also maintain higher dessert quality and reduce incidence of superficial scald after long-term cold storage (Chen, 2004).

A stepwise low O₂ CA procedure was introduced by Chen and Varga (1997) in which ‘d’Anjou’ pears are stored in 0.8% O₂ + <0.1% CO₂ at −1°C for 3–4 months before transfer to standard CA. Low O₂ effectively controls superficial scald without inducing “black speck” and “pithy brown core.” For superficial scald control, the primary method is a postharvest ethoxyquin treatment with a dosage of 2700 ppm. Chen and Varga (1997) combined CA and ethoxyquin for superficial scald control. They showed ‘d’Anjou’ fruit destined for mid term (5–6 months) or long term (7–8 months) can be stored in CA (1.5 kPa O₂ and <0.5 kPa CO₂ throughout the entire storage period) plus a reduced ethoxyquin dosage (1000 ppm). Ethoxyquin needs to be applied within 2 days.

CA storage regimes for pears are similar to apples, and dynamic CA has a potential to maintain a better quality in extended storage (Prange et al., 2002, 2003, 2005a,b).

12.2.2.3 Pear Ripening

Most pear cultivars require a chilling period after harvest to gain ripening ability. Storage duration at −1°C, which is required to induce normal ripening of pear fruit, is 2–4 weeks for ‘Bartlett’ (Agar et al., 1999), 2–3 weeks for ‘Bosc’ (Chen et al., 1982), and 7–8 weeks for ‘d’Anjou’ (Chen et al., 1982). After receiving enough chilling units, fruit readily ripen at ambient temperatures. The best ripening temperature range is about 15°C–21°C. Higher or lower temperatures result in poorer quality or excessive decay (Prange et al., 1988). Most cultivars fail to ripen at 30°C or above.

Freshly harvested winter pears do not produce ethylene (Wang et al., 1985). Exposure of pears to cold storage stimulates synthesis of 1-aminocyclopropane-1-carboxylic acid (ACC) because low temperature induces biosynthesis of ACC oxidase and ACC synthase (Wang et al., 1985; Lelièvre et al., 1997). Exogenous ethylene, at 100 μL L⁻¹, has been used commercially to precondition underchilled ‘Bartlett’ and ‘d’Anjou’ pears at 20°C for 2–3 days before shipment. Preconditioned pear fruits are capable of ripening normally and uniformly upon reaching the retail markets or for the canning process (Chen et al., 1996; Agar et al., 1999).

1-MCP has been considered a potential tool to extend storage life of pears. However, Chen and Spotts (2006) report that when 1-MCP dosage is 30 μL L⁻¹ or higher, pear fruit loses its normal ripening ability; on the other hand, when 1-MCP dosages are 20 μL L⁻¹ or lower, superficial scald cannot be controlled after 4 months of cold storage. ‘Bartlett’ pears are less sensitive to 1-MCP in comparison with ‘d’Anjou’ (Bai et al., 2006). Bai et al. (2006) reinitiated the ripening ability of 1-MCP-treated ‘Bartlett’ pears by holding fruit at 10°C–20°C for 10–20 days. However, it is difficult to ripen 1-MCP-treated ‘d’Anjou’ pears (Bai et al., 2006).
12.2.3 MAP

Because pears are sensitive to high \( \text{CO}_2 \), and because \( \text{CO}_2 \) concentration in MAP is generally high and difficult to control, there is very limited commercial use for this technology. In CA storage, 'd'Anjou' pears should be stored with the oxygen at least 1 kPa higher than the \( \text{CO}_2 \) at all times. However, there has been some research indicating fruit stored at >1°C can tolerate higher \( \text{CO}_2 \) levels. Sugar (2001) reported that 'Comice' in MAP (~4 kPa \( \text{O}_2 + 4 \) kPa \( \text{CO}_2 \)) maintains storage life for 4–5 months with a comparable quality to those held in standard CA (2 kPa \( \text{O}_2 + <1 \) kPa \( \text{CO}_2 \)). Similarly, 'Bosc' pears can be stored for 5 months successfully (MAP: 3 kPa \( \text{O}_2 + 4 \) kPa \( \text{CO}_2 \)), but low \( \text{O}_2 \) and/or high \( \text{CO}_2 \) injury is observed after 6 months. Low \( \text{O}_2 \) and/or high \( \text{CO}_2 \) injury is also observed in MAP-stored 'Starkrimson' (1–2 kPa \( \text{O}_2 + 4–5 \) kPa \( \text{CO}_2 \)), 'Bartlett' (1–2 kPa \( \text{O}_2 + 4–5 \) kPa \( \text{CO}_2 \)), and 'd'Anjou' (4 kPa \( \text{O}_2 + 4 \) kPa \( \text{CO}_2 \)) pears while fruit stored in standard CA (2 kPa \( \text{O}_2 + <1 \) kPa \( \text{CO}_2 \)) maintain good quality (Sugar, 2001).

12.2.4 Edible Coating

According to the Kupferman (1998) survey in Washington, Oregon, and California, which produce more than 90% of U.S. pears, edible coatings are applied on 71% 'd'Anjou,' 25% of 'Bartlett,' and 26% of 'Bosc' fruits. Carnauba-based waxes are the major coatings for pears, but sucrose fatty acid ester and shellac are also used by some packers in some cultivars. Carnauba waxes used in pears are specially formulated for pears or diluted apple waxes. Pear wax has less total solids than apple wax, because a high gas barrier may cause anaerobic metabolism in pears, and disrupt the ripening.

Amarante (1998) and Amarante and Banks (2001) showed that differences in skin structure of pears affect coating performance significantly. For cultivars without lignified cells in the skin ('Bartlett,' 'Comice,' and 'Packham's Triumph'), the diffusion of water vapor, \( \text{CO}_2 \) and \( \text{O}_2 \) decreases markedly with a small increase in the total solids in a carnauba wax, because the coating covers the entire skin surface, including lenticels (Figure 12.3). However, for 'Bosc' pears, which characteristically have lignified cells in the

**FIGURE 12.3**

Hypothetical model for the differences in skin permeance to \( \text{O}_2 \) (arrow with dotted line), \( \text{CO}_2 \) (arrow with dashed line), and water vapor (arrow with solid line) in a non-coated (A) and a coated (B) pear without lignified cells in the skin. Arrow size is proportional to the differences in permeance values (cr = crack in the cuticle; c = cuticle; e = epidermis; I = lenticel; se = sub-epidermis; w = wax coating layer). (From Amarante, C., Gas Exchange, Ripening Behaviour and Postharvest Quality of Coated Pears, PhD dissertation, Massey University, Palmerston North, New Zealand, 1998. With permission.)
only the diffusion of CO₂ and O₂ markedly decreases, whereas the water vapor diffusion decreases little by increasing the total solids content. This was because almost all O₂ and CO₂ exchange occurs through the lenticels, and the coating effectively covers them; on the other hand, increasing the coating concentration is not effective in covering the lignified cells in the epidermis which is the major pathway for water vapor exchange (Figure 12.4).

12.3 Asian Pear

Asian pears were developed from Pyrus ursuriensis (cold tolerance, Northeast China and North Korea), P. bretschneideri (temperate-zone, Central China), and P. pyrifolia (warm rainy regions, South China, South Korea, and Japan). Asian pears are eaten at a firm and crisp stage right after harvest or after cold storage. The texture is like a very crisp and juicy apple. They are also known in the United States as Chinese pears, Japanese pears, and sand or apple pears. There are three types of Asian pears in appearance. They are (1) round or flat fruit with green-to-yellow skin (‘Nijisseiki’ and ‘Shinseiki’), (2) round or flat fruit with bronze-colored skin and a light bronze-russet (‘Hosui’ and ‘Shinko’), and (3) pear-shaped fruit with green or russet skin (‘Ya Li’ and ‘Kuerle’). Some cultivars, such as ‘Nijisseiki,’ ‘Kosui,’ and ‘Niitaka’ have a nonclimacteric respiratory pattern and produce little ethylene (<0.1 μL kg⁻¹ h⁻¹). Other cultivars, such as ‘Yali,’ ‘Tsu Li,’ ‘Hosui,’ ‘Kikusui,’ and ‘Chojuro’ have a climacteric respiratory pattern and produce ethylene up to 9–14 μL kg⁻¹ h⁻¹ (‘Ya Li’ and ‘Tsu Li’) or 1–3 μL kg⁻¹ h⁻¹ (other cultivars) at 0°C (Crisosto, 2004).

12.3.1 Maturity and Harvest

Most growers determine harvest time by fruit taste and color. Sugar content over 12.5% usually is adequate and fruit pressure of 35.5–49 N (8–11 lb) seems satisfactory. Fruit pressure is not as good a measure of maturity in Asian pears as it is in European pears. The color of russet-type fruit changes from green to brown, and the ground color of green fruit changes from green to yellow. Color and sugar content best determine time to harvest.
Some green Asian pears, such as ‘Ya Li’ do not change color much at maturity. All Asian pears must be carefully handled to minimize bruising and brown marks and stem punctures. Overmature fruit quickly show roller bruises, fingerprints, and other signs of handling at harvest. Undermature fruits are poor in flavor and ruin the market for Asian pears. Multiple harvests are necessary to get mature, quality fruit from most cultivars. Asian pears are harder to handle than European pears and they are not suited to large, fast-moving packinghouse lines. Fruit is best field-packed from picking containers to packing boxes or trays.

12.3.2 Storage Regimes

12.3.2.1 Temperature

Optimum storage conditions are 0°C ±1°C with RH of 90%-95% (Crisosto, 2004). The actual freezing temperature is influenced by SSC of the fruit; at soluble solids levels of 10–12%, the freezing points would be approximately -1.7°C to -2.2°C. Asian pears are susceptible to water loss. When water loss has been higher than 5%-7%, fruits become dehydrated and have a shriveled appearance, especially the ‘Kosui’ and ‘Hosui’ varieties. After 2–3 months ‘Hosui’ and ‘Shinko’ fruits get spongy, show some storage rot, and after 4 months, may show internal breakdown in the core area. Less mature fruits get spongy sooner than the fully mature fruit. At room temperature of 20°C, the fruit begins to soften or get spongy after 14–21 days.

12.3.2.2 CA Consideration

Based on limited studies, it appears that the magnitude of CA benefits for Asian pears is cultivar-specific and is generally less than that of European pears and apples. O₂ levels of 1-3 kPa for ‘Nijisseiki’ and 3%-5% for ‘Ya Li’ help retain firmness and delay changes in skin color. Asian pears are sensitive to CO₂ injury (>2 kPa for most cultivars) when stored for more than 1 month.

References

AgroFresh Inc. 2007. Factors Affecting Apple Crunch—How to Optimize Storage for Fruit of Varied Quality Levels. AgroFresh Inc., Springhouse, PA.


