Postharvest physiology and technology of Annona fruits

Sunil Pareeka, Elhadi M. Yahia b,⁎, O.P. Pareekc, R.A. Kaushika

Department of Horticulture, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture & Technology, Udaipur, Rajasthan, 313 001 India
Faculty of Natural Sciences, Autonomous University of Queretaro, Avenida de las Ciencias S/N, Juriquilla, 76230, Queretaro, Mexico
Central Institute for Arid Horticulture, Indian Council for Agricultural Research, Bikaner, Rajasthan, India

ABSTRACT

Annona comprises many species but 5 of them are of significant commercial importance, namely the custard apple, cherimoya, soursop, bullock’s heart and atemoya. The postharvest system for these fruits is not yet adequately developed, and therefore several handling problems are still common. Rapid softening of fruits after harvest, especially during transportation and marketing is a major ongoing problem. Annonas are climacteric fruit, generally characterized by high respiration and ethylene production, and are chilling sensitive. Extended fruit storage periods are still not possible, mainly because of the high susceptibility to chilling injury. Although still limited, there has been some postharvest research on these fruits in the last 2–3 decades, but scattered in diverse sources, especially local and regional sources and in several languages, and therefore this review attempts to outline some of the important findings, especially on maturity and harvesting indices, respiration, ethylene production, ripening changes, different treatments to extend the storage and shelf life of the fruit.

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⁎ Corresponding author. Tel.: +52 442 1921200x5354; fax: +52 442 2342951/8.
E-mail addresses: sunil_ciah@yahoo.co.in (S. Pareek), yahia@uaq.mx (E.M. Yahia), pareek_o@yahoo.com (O.P. Pareek), kaushik_ra@yahoo.co.in (R.A. Kaushik).
1. Introduction

Annona fruits are of the world’s best tasting fruits, due to the sweet, creamy flesh and fragrant flavor when fully ripe. Out of 100 species of Annona, only 5 species, namely the custard apple, cherimoya, soursop, bullock’s heart and atemoya are of major commercial importance. There have been studies on the postharvest changes that occur in Annona fruits but there are still many problems that have to be solved. Rapid softening of fruits during transportation and at retail stores is the biggest ongoing problem. Generally it is recognized that Annonas are climacteric fruits. Extended fruit storage is still not possible, mainly because of the high susceptibility to chilling injury, and therefore the requirement for relatively high holding temperatures. Ripening of Annona fruits is characterized by high respiration and high ethylene production rates. A review has been published in 1993 (Palma, Aguilera, & Stanley) on postharvest events of cherimoya fruits. However, in the last 17 years important new research on postharvest physiology and technology have been published although scattered in different sources in different languages, and therefore we attempt here to review several important aspects such as maturity and harvesting indices determination, respiration, ethylene production, ripening changes, treatments to extend the storage and shelf life of the fruit including the use of modified and controlled atmospheres, and other important postharvest information generated on the five species of Annona.

2. Scientific, common names and synonymies

The family Annonaceae Juss. covers more than 119 genera with more than 2000 species, grouped taxonomically, and widespread in the subtropics and tropics (Geurts, 1981). Seventeen genera of these are distributed in tropical areas, and only four genera, Annona, Rollinia,

Table 1
Botanical or specific, common and vernacular names and their synonyms of the five Annona species studied.
Source: Pisto et al. (2005).

<table>
<thead>
<tr>
<th>Botanical</th>
<th>Synonyms</th>
<th>Common</th>
<th>Other common names</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. cherimola Mill.</td>
<td>A. tripetala Aiton, A. pubescens Salisb.</td>
<td>Cherimola, Cherimoya</td>
<td>Cherimoya, anona del Peru, cherimoya del peru, catuche, momora (Spanish), cherimolier (French), cherimoya, cherimoyer, annona, custard apple (English), hanumanaphal (Kannada), lakshmanapal (India), noina ostrelia (Thai), anon (Spanish, Guatemalan), cherimolia, anona do chile, cedea de negro (Portuguese), cerimolia (Italian), chirimoyaboom peruanischer flaschenbaum, flachbaum (German)</td>
</tr>
<tr>
<td>A. muriata L.</td>
<td>A. muriata L. A. bonplandiana Kunth; A. cearensis Barb. Rodr.; A. macrocarpa Weerckle; A. muriata var. borinquensis Morales; Guanabana muricuta Gomez</td>
<td>Soursop</td>
<td>Guanabana (Spanish), corosolier (French), zuurzak (German), munnola (India), multuseeta pullupala (Tamil), mullu ramaphala (Kannada), multananchaka, vilathinuru (Malayalan), graaviola (Portuguese), durian belanda (Malayalan), mammon (Spanish, Philippines)</td>
</tr>
<tr>
<td>A. reticulata L.</td>
<td>A. excoo Kunth; A. laevis Kunth; A. longifolia Moc. and Sesse; A. riparia Kunth.</td>
<td>Custard apple</td>
<td>Bullock’s heart, Corazon (English), condessa e coracao-de-boi (Portuguese), buah nona (Indonesian), ramphal (India), ramaseeta (Tamil), ramasitapala (Tegelu), vilathi (Malayalan), ramaphala (Kannada)</td>
</tr>
<tr>
<td>A. senegalensis Pers.</td>
<td>A. arenaria Thonn.; A. chrysophylla Boj.; A. chrysophylla var. porpetac Bail.; A. senegalensis var. porpetac Bill. wild</td>
<td>Wild soursop</td>
<td>Mchekwa (Kishwahili), motomoko (Kichaga), mtotetope (Kirifi), gishta gaba (Arabic), annone (African), pomme cannelle du Senegal (French), nhokononwitu, nwotkwe,mtopa (Zammbia), gishta (Ethiopia), dau-ha, dyangara (Bambara), moupa (Dierma), bu bualambu, goritsaatibu, iuboualansahu (Gourmancho), barkudugo, bakikugida, barduki, barkudugo, barkoudouga (Moore), barkoutahe, dokudugo, barkoutahe, dokumi, doukoubi (Peuhl), digor, dagor, jorguat (Wolof), Sweesop, sugar apple, custard apple (English), ata, pinha or fruta do conde (Portuguese, Brazil), attire (French), saramuya and Aztec (Mexico), sitaphal (Tamil), seethapalam, atithchakku (Malayalan), nana sri kaya (Malayasan), seethapandu (Tegelu), amritphala, seethphala (Kannada), aatoa, shariffa, sitaphal (Hindi), ata luna (Bengali), noina (Thai)</td>
</tr>
<tr>
<td>A. squamosa L.</td>
<td>A. asiatica L.; A. cinerea Dunal; Guanabana squamosus Gomez</td>
<td>Sugar apple</td>
<td>Sugar apple, custard apple (English), aseh and fragrant (Arabic), choon (Mandarin), musam (Indonesian), pru murni (Malaysian), amritphala (Hindi), amritphal, sitaphala (Kannada), amritphala, sitaphala (Hindi), amritphala, sitaphala (Kannada), aatoa, shariffa, sitaphal (Hindi), ata luna (Bengali), noina (Thai)</td>
</tr>
</tbody>
</table>
Uvaria and Asimina produce edible fruits (Ochse, Soule, Dijkmann, & Wehberg, 1974).

The genus Annona L. Syst. ed. I. (1735) comprises around 120 species, as well as a number of hybrids commonly referred to as Atemoyas. The species of this genus have one of the most delicately flavored fruits when properly ripened. The flesh has a pleasant blend of sweetness and mild acidity with a consistency of baked custard. This distinguishes characteristics of the cherimoya and related to the peculiar taste as result of the harmonic combination of acids and sugars. The cherimoya fruit contains remarkable amounts of calcium, phosphorus, carbohydrates, thiamine, riboflavin, fructose, glucose, sucrose, cellulose, hemi-cellulose, lignin and peptic substances (Table 2).

<table>
<thead>
<tr>
<th>Components</th>
<th>Cherimoya</th>
<th>Custard apple</th>
<th>Soursop</th>
<th>Sugar apple</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (g)</td>
<td>77.3±3</td>
<td>75.8±2.8</td>
<td>81±2.5</td>
<td>72.6±2.4</td>
</tr>
<tr>
<td>Proteins (g)</td>
<td>1.6±0.6</td>
<td>1.85±0.05</td>
<td>1±0.55</td>
<td>1.68±0.8</td>
</tr>
<tr>
<td>Lipids (g)</td>
<td>0.1±0.2</td>
<td>0.35±0.15</td>
<td>0.6±0.3</td>
<td>0.4±0.3</td>
</tr>
<tr>
<td>Carbohydrates (g)</td>
<td>18.4±2.4</td>
<td>18.7</td>
<td>17.25±0.1</td>
<td>19.3±1</td>
</tr>
<tr>
<td>Fiber (g)</td>
<td>1.64±0.5</td>
<td>2.55±0.35</td>
<td>0.86±0.1</td>
<td>1.4±0.6</td>
</tr>
<tr>
<td>Total acidity (g)</td>
<td>0.58±0.19</td>
<td>10.4±0.3</td>
<td>7.5±0.3</td>
<td>1.0±0.3</td>
</tr>
<tr>
<td>Ash (g)</td>
<td>0.7±0.1</td>
<td>0.95±0.15</td>
<td>0.61±0.2</td>
<td>0.7±0.1</td>
</tr>
<tr>
<td>Energy (calories)</td>
<td>68.6±13.4</td>
<td>75</td>
<td>65±5</td>
<td>96±10</td>
</tr>
<tr>
<td>Calcium (mg)</td>
<td>27.1±5.7</td>
<td>24</td>
<td>15±7</td>
<td>26±2</td>
</tr>
<tr>
<td>Phosphorous (mg)</td>
<td>35.2±18</td>
<td>26</td>
<td>28±1</td>
<td>42±14</td>
</tr>
<tr>
<td>Iron (mg)</td>
<td>0.6±0.2</td>
<td>1</td>
<td>0.7±0.1</td>
<td>0.8±0.5</td>
</tr>
<tr>
<td>Vitamin A (mg)</td>
<td>–</td>
<td>Traces</td>
<td>14.45±5.45</td>
<td>0.007±0.001</td>
</tr>
<tr>
<td>Vitamin B1 (mg)</td>
<td>0.09±0.03</td>
<td>0.07</td>
<td>0.07±0.01</td>
<td>0.1±0.01</td>
</tr>
<tr>
<td>Vitamin B12 (mg)</td>
<td>0.12±0.2</td>
<td>0.12</td>
<td>0.08±0.035</td>
<td>0.13±0.05</td>
</tr>
<tr>
<td>Ascorbic acid (mg)</td>
<td>11.5±5.5</td>
<td>30</td>
<td>19.4±3</td>
<td>37.38±4.62</td>
</tr>
<tr>
<td>Tannins (mg)</td>
<td>–</td>
<td>–</td>
<td>85.30</td>
<td>–</td>
</tr>
</tbody>
</table>

Data are means ± standard deviation, and ranges are indicated in parenthesis.

3. Fruit composition

The cherimoya fruit contains remarkable amounts of calcium, phosphorus, carbohydrates, thiamine, riboflavin, fructose, glucose, sucrose, cellulose, hemi-cellulose, lignin and peptic substances (Table 2). The cherimoya is very digestible and nutritious with a peculiar taste as result of the harmonic combination of acids and sugars. The cherimoya fruits to ripen on the tree, because they fall and lose market quality. Although harvesting after 104 days from artificial pollination doubled the shelf life at the peak of ethylene production (Paull, 1982). At a later stage, the fruit was soft with a slight off odor, and correlated with a decline in titratable acidity and total phenols.

After 104 days from artificial pollination, sugar apple fruit showed good features for consumption, ripened after 6 days after harvest, whereas the fruit reaped at 108 days after artificial pollination had only three days shelf life (Pereira, Bres, Nietsche, & da Mota, 2010). Although harvesting after 104 days from pollination doubled the shelf life compared to when reaped at 108 days, fruit pulp weight showed an increase of around 50 g, which represents approximately 7% of the fruit pulp. Sugar apple fruits are considered to be mature and ready for consumption. The pleasant smell is the product of odor-active volatiles mostly produced by the leucine pathway (Lizana & Reginato, 1990).

A. muricata fruit contain 85.5% pulp, 3.3% seeds, 8.9% skin and 2.9% of a fleshy receptacle (Paull, 1982). The sourpuff fruit taste is the result of the combination of sugars and organic acids (0.65–0.85%), of them, the most important being malic and citric acids in a ratio of 2:1 (Morton, 1987).

A. reticulata flesh is creamy yellow, rich and sweet, with low acidity (Wester, 1913). However, its flavor is not considered comparable to that of cherimoya or sugar apple (Pinto et al., 2005).

4. Maturity indices and harvest

According to season two distinct vegetative flushes are commonly found in Annonaceous fruits. Therefore, harvest time based on anthesis is impractical, because flowering can occur during several months. On the other hand time of hand pollination can alter the time of harvesting (Pinto et al., 2005). Sugar apple fruits are considered to be mature and reach their harvesting point when the skin changes color and when the segments spread far apart, exposing a creamy yellow skin (Salunkhe & Desai, 1984). Premature harvesting can result in poor fruit quality, and fruits left to ripen on the tree are often eaten by birds and bats, and when over-mature they have a tendency to break and decay (Corneal, 1994; Lucas, 1994; Mosca, Assis, Alves, Filgueiras, & Batista, 1997; Salunkhe & Desai, 1984).

Changes of skin color from dark green to light green or greenish-yellow are the primary maturity index in cherimoya, atemoya, sweetsop and custard apple (Pal & Kumar, 1995; Pinto et al., 2005). Other indicators include appearance of cream color between segments on the skin and increased surface smoothness of the separate fruit carpels (Kader & Arpaia, 2006). The time of harvesting is commonly determined by the fruit skin color, which changes with the proximity of physiological maturity. At harvesting time, sourpuff fruit skin changes from dark green to slightly yellowish green, but in all cases their pulp should be firm (Nakasone & Paul, 1998).

Sourpuff fruits loose shine and the skin color changes from dark green to light green with maturation (Accorsi & Manica, 1994; Salunkhe & Desai, 1984; Torres & Sanchez, 1992). The carpel units spread apart when the fruits are mature. In Colombia, growers and wholesalers press the fruit with their thumbs to check the fruit maturity (Torres & Sanchez, 1992). The optimal eating stage occurred at day 5 to 6 from harvest at the peak of ethylene production (Paull, 1982). At a later stage, the fruit was soft with a slight off odor, and correlated with a decline in titratable acidity and total phenols.
reach their harvesting point when the skin changes color and when the segments spread far apart, exposing a creamy yellow skin (Salunkhe & Desai, 1984). In India it is harvested at the fully mature stage when it develops a creemish-green skin color with valleys between areoles turning yellowish (Vishnu Prasanna, Sudhakar Rao, & Krishnamurthy, 2000). Skin color can be used as maturity index in sugar apple. For local markets, fruits should be harvested when mature, with 20 to 40% yellowish-green skin, and they will ripen in 4 to 6 days; however, for export market 10 to 20% yellowish-green skin is satisfactory. When fruits are harvested with more than 75% yellowish-green skin, they will ripen in 1 to 3 days, while fruits harvested at less than 5% do not ripen at all (George, Nissen, & Brown, 1987). Therefore, the intensity of color development determines the purpose of harvest and ripening duration.

Cherimoya fruits are generally harvested when the skin color changes from green to yellowish-green (Accorsi & Manica, 1994; De La Plaza, 1980; Reginato, 1980). However, sometimes the change in skin color is not very pronounced. Consequently, color change, pollination time, and fruit size are not reliable harvest indices (Pinto et al., 2005). Nomura et al. (1997) have shown that in ‘Big Sister’ cherimoya age and weight are not good harvest indices, as maturity will depend on climatic conditions during growth. Changes in color and/or density of epidermal trichomes were shown to be indicative of early stages of maturity (Herrera, 1988; Tietz, 1988). Color values over L* (lightness) 55.5 and Chroma of 36 allow the development of as acceptable quality for export fruit of cherimoya (Berger & Galletti, 2005). High correlation was observed between soluble solids evolution and fruit diameter during growth (Pavez, 1985). The development of flavor of ripe cherimoya was correlated with higher soluble solids content whereas pulp firmness was not found to be predictive of maturity (Tietz, 1988). Looseness of seeds inside the fruit has also been used as a guide to maturity. Therefore, the harvest index needs to be improved for cherimoya to ensure better fruit consistency, flavor and quality (Alves, Filgueiras, & Mosca, 1997; Nakasone & Paul, 1998; Nomura et al., 1997; Palma, Aguilera, & Stanley, 1993).

5. Physiological and biochemical changes during ripening

5.1. Respiration

The climacteric nature of the ripening of Annonaceous fruit was reported by Biale and Barcus (1970). They ascribed the irregular increase in oxygen consumption after harvest to the structure of the fruits being ‘aggregates of many ovaries’, reflecting changes of variable tissues in several physiological stages. Some studies (Broughton & Tan, 1979; Brown, Wong, George, & Nissen, 1988; Kosiyachinda & Young, 1975; Morena & De La Plaza, 1993; Paul, 1982) have confirmed the irregular shape of the respiratory curve of harvested Annona fruit, and also showed that the increase in ethylene evolution lags days behind the onset of the respiratory rise. Cherimoya and atemoya fruits showed two successive rises in respiration rate whereas sugar apple fruits showed only one (Brown et al., 1988).

Atemoya is a fruit with a typical climacteric maturation characterized by a rise in respiration rate (Brown et al., 1988; Morena & De La Plaza, 1993). Mature soursop fruit produced a biphasic respiratory climacteric, with CO₂ production reaching 100 mL kg⁻¹ h⁻¹ and then 350 mL kg⁻¹ h⁻¹ at 25–30 °C (Desmond, Worrill, Carrington, & Huber, 1994). The maximum respiration rate was 108 mL kg⁻¹ h⁻¹ during ripening of soursop fruit (Paul, 1982). Soursop fruit showed increased CO₂ production 2 days after harvest, preceding the respiratory increase that coincided with autocalytic ethylene evolution and other ripening phenomena. The respiratory quotient of tissue disks was near unity throughout development. Tricarboxylic acid cycle members and ascorbate were more effective substrates than sugars, but acetate and glutarate were strongly inhibited. Disk respiration showed the same early peak as whole fruit respiration; this peak is thus an inherent characteristic of postharvest development and cannot be ascribed to differences between ovaries of the aggregate type fruit. The capacity of the respiratory apparatus did not change during this preclimacteric peak, but the contents of rate-limiting malate and citrate increased after harvest (Bruinsma & Paul, 1984). Authors concluded that the preclimacteric rise in CO₂ evolution reflects increased mitochondrial respiration because of enhanced supply of carboxylates as substrates, probably induced by detachment from the tree. The second rise corresponds with the respiration during ripening of other climacteric fruits (Bruinsma & Paul, 1984).

In a respiratory study of ‘Booth’ cherimoya at 15 °C, Biale, Young, and Olmstead (1954) found that the fruit had a peak respiratory climacteric (approximately 63 mL CO₂ kg⁻¹ h⁻¹) after 4 to 5 days from harvest (Brown et al., 1988). Kosiyachinda and Young (1975) studied ‘Chaffey’ cherimoya and found that it had two peaks of CO₂ production, one 5 days after harvest (approximately 90 mL CO₂ kg⁻¹ h⁻¹) and a second larger peak after 10 days (approximately 180 mL CO₂ kg⁻¹ h⁻¹). They found that the fruit softened and developed characteristic flavor and aroma during the second respiratory rise and was at its best edible condition on day 6. Fruit from early, mid and late harvest dates, either non-stored or previously cold stored, showed a climacteric-like pattern of respiration at 20 °C (Alique & Zamorano, 2000). The time of climacteric peak was not influenced by harvest date and occurred approximately on the 3rd day (Alique & Zamorano, 2000). Nomura et al. (1997) also found that the age of ‘Big Sister’ cherimoya did not influence the maximum respiration rate during ripening. However, Kosiyachinda and Young (1975) found that the average time from harvest to the onset of the respiratory rise was much longer in early harvested (January) than in late harvested ‘Chaffey’ cherimoya. This disagreement between findings may be due to the great differences in the climatic conditions during the development of California grown ‘Chaffey’ and Spain grown ‘Fino de Jete’ cherimoyas, and in the postharvest physiology of the two cultivars. Rise in respiration of cherimoya fruit is not triggered by ethylene, although it may have a role in regulating the climacteric period (Alique & Zamorano, 2000; Kosiyachinda & Young, 1975; Merodio & De La Plaza, 1997; Palma et al., 1993).

Broughton and Tan (1979) found that at 20 °C, the onset of increased rates of CO₂ and C₂H₄ production of sugar apple both occurred about 3 days after harvest, but the peak of the respiratory climacteric (at 7 days) occurred about 1 day before the ethylene climacteric. The CO₂ emission rates for mature sugar apple fruit was 1.42% (Da Silva et al., 2001). ‘Balanagar’ sugar apple fruits stored at 25 and 20 °C had a clear climacteric peak whereas those stored at 15 and 10 °C did not show any distinct rise in respiration rate (Vishnu Prasanna et al., 2000). A high respiration velocity was found with a climacteric maximum of 243.1 mL CO₂ kg⁻¹ h⁻¹, 3 day after harvest (Bolivar-Fernandez, Saucedo-Veloz, Solis-Pereira, & Sauri-Duch, 2009).

5.2. Ethylene production

Ethylene production showed one main peak but the onset of rapid production occurred after the beginning of the respiratory climacteric in cherimoya, atemoya and sugar apple (Brown et al., 1988). The ethylene emission rate was significantly higher in the mature (2.77 μL kg⁻¹ h⁻¹) than in the immature (0.054 μL kg⁻¹ h⁻¹) stage in sugar apple fruits as determined by infrared absorption techniques (Da Silva et al., 2001). The ethylene released by ‘Balanagar’ sugar apple fruits stored at ambient temperature showed an increase on day 2 of harvest and reached a maximum (2.38 μL kg⁻¹ h⁻¹) on day 3, coinciding with the respiration peak (Vishnu Prasanna et al., 2000). Ethylene production at respiratory maximum after 3 days of harvest in sugar apple fruits was lower than 1.0 μL kg⁻¹ h⁻¹ (Bolivar-Fernandez et al., 2009).

Ethylene production increased 24 to 48 h after the soursop fruit climacteric was initiated (Paul, 1982). The onset of the rise in ethylene
production in soursop fruit occurred 3 days after harvest i.e., later than the onset of the respiration climacteric (approximately 150 mL ethylene kg⁻¹ h⁻¹), which occurred 7 days after harvest (Brown et al., 1988). Peak of ethylene production (250–350 mL kg⁻¹ h⁻¹) occurred between the two respiratory maxima (Desmond et al., 1994).

Cherimoya fruit stored at 20 °C softened rapidly within 5 days and displayed a typical climacteric and ethylene production patterns (Li et al., 2009). The onset of the increase in ethylene production of cherimoya fruit occurred after the climacteric rise in respiration (Alique & Zamorano, 2000; Kosiyachinda & Young, 1975; Nomura et al., 1997; Palma et al., 1993; Sanchez, Zamorano, & Alique, 1998). The internal ethylene concentration of 'Chaffer' cherimoya fruit was less than 0.05 ppm until the midpoint of the first respiratory rise (at about day 4). The onset of the rise in ethylene production occurred at about 7 days after harvest (Broughton & Tan, 1979). Production of ethylene was dependent on storage temperature of the fruit having maximum values of 46.2 ± 2.7 μL L⁻¹ Kg⁻¹ h⁻¹ in cherimoya stored at 20 °C and 1.91 ± 0.03 μL L⁻¹ Kg⁻¹ h⁻¹ when they were stored at 10 °C (Lahoz et al., 1993). The highest ethylene production was observed at 15 and 20 °C and was restricted at 30 °C and 35 °C in 'Libby' cherimoya fruit. Yonemoto, Hagiwara, and Tomita (1997) indicated that there was a difference in the maximum rate of ethylene production among 19 cherimoya cultivars, but no difference in the number of days to their ethylene peak. Ethylene production in cherimoya fruit increased after 2 days in storage, and reached a peak (approximately 68.5 mL C₄H₄ L⁻¹ Kg⁻¹ h⁻¹) after 5 days at 20 °C (Shen, Li, Chen, Xie, & Lu, 2009).

5.3. Total soluble solids (TSS)

TSS, which are mostly made of sugars, increased from about 10 °B to near 16 °B during 3 days of ripening in soursop fruit (Paul, 1982). In cherimoya, it increased from about 8.3 °B to 22 °B during 4 days of ripening at 22 °C. Similar values in TSS did not reach until the 10th day at 12 °C. Fruit stored at 4 °C underwent a slower increase in TSS. Storage at 1 °C for 27 days resulted in an increase in TSS by only 2 °B. Fruit re-warmed to 22 °C after storage for 11 days at 4 °C underwent changes in TSS similar to those found in fruit placed directly into 22 °C air (Gutierrez, Sola, Pascaul, & Vargas, 1994). The TSS contents of sugar apple fruits increased during storage at different temperatures (Bolivar-Fernandez et al., 2009; Vishnu Prasanna et al., 2000). It can be concluded that TSS increase with the increase in storage duration and the rate of increase is higher at higher temperatures.

5.4. Acids

Ripening of soursop fruit resulted in a 7-fold increase in malic acid and a 3-fold increase in citric acid (Paul, Deputy, & Chen, 1983). Both acids peaked 3 to 4 days after harvest, and then declined. A slight increase in acidity was shown during the initial stages of ripening followed by a decrease in sugar apple fruits (Bolivar-Fernandez et al., 2009; Vishnu Prasanna et al., 2000). The increase in acidity can be ascribed to the production of organic acids during ripening of cherimoya (Gutierrez, Lahoz, Sola, Pascaul, & Vargas, 1994) and soursop fruits (Paul et al., 1983).

5.5. Ascorbic acid

Ascorbic acid increased 11-fold during ripening in soursop fruit (Paul, 1982). It increased slightly during the initial stages of ripening followed by a decline during storage at different temperatures in sugar apple fruits (Vishnu Prasanna et al., 2000). Broughton and Tan (1979) also reported an increase in ascorbic acid content in sugar apple as the fruit ripened, reaching a maximum at the climacteric, after which the amount decreased.

5.6. Sugars

In soursop, sucrose increased 4-fold at maturity and maximum concentration occurred 3 days after harvest, and then declined to 40% of the peak value (Paul et al., 1983). Fructose and glucose increased slowly to a peak 5 days after harvest. The ratio of sucrose, glucose, and fructose at the edible ripe stage was 4.3:3.0:3.2. Starch breakdown leading to sugar and organic acid production occurred before any rise in ethylene production. This breakdown of starch may be an important initiating event in the ripening of soursop fruit. Total ethanol soluble sugars increased 2 fold during ripening (Paul, 1982). The continuous increase in sugars content during storage was observed by Vishnu Prasanna et al. (2000), and the changes were more rapid at 25 and 20 °C than at 15 and 10 °C.

5.7. pH

Soursop fruit pH declined from 5.8 to 3.6 with a concomitant increase in titratable acidity during 3 days of ripening period (Paul, 1982). The fruit pH of cherimoya during 4 days of ripening at 22 °C declined from 6.2 to 4.3. Similar decline in pH did not reach until the 10th day at 12 °C. The decrease in pH was less than 1 unit in fruits stored at 4 °C, and storage at 1 °C for 27 days did not modify it (Gutierrez, Lahoz, Sola, Pascaul, & Vargas, 1994). The decrease in pH during ripening of sugar apple fruit was also noted by Bolivar-Fernandez et al. (2009).

5.8. Volatiles

Head space volatile production in soursop fruit began to increase 3 days after harvest and peaked 2 days later (Paul et al., 1983). This peak corresponded with the peaks in total sugars, organic acids, and the edible ripe stage when individual fruit results were compared on the basis of the start of the climacteric respiratory increase. After the peak in volatile production, there was a dramatic drop over the next 3 days in major fruity esters produced, with a gradual increase in volatiles, which probably imparted the off-odor of the overripe fruit.

5.9. Phospholipids

Senescence of 'Fino de Jete' cherimoya was characterized by a decrease in phospholipids content, and twenty different fatty acids were identified (Gutierrez, Sola, & Vargas, 2005; Margarita, Sola, & Vargas, 2005). The C16:0, C18:0, C18:1, C18:2n-6 and C18:3n-3 fatty acids were the most abundant and the C18 family comprised more than 50% of total fatty acids. Major variations in the relative composition of mesocarp phospholipid fatty acids were observed during the pre-climacteric stage. These changes did not modify the un-saturation index of the membrane but increased the un-saturation level for C18 fatty acids class. The modification of the relative quantity of specific polyunsaturated fatty acids in phospholipids was more relevant than the total content of fatty acids for the adaptation of mesocarp membranes to ripening and senescence processes in cherimoya fruit.

5.10. Firmness

Very little is known about the mechanical properties of cherimoya fruit and how they are affected during storage (Palma et al., 1993). Most researchers use penetration tests to evaluate cherimoya softening (Alique, Zamorano, Calvo, Carmen, & De La Plaza, 1994; Brown et al., 1988; Martinez, Serrano, Pretel, Requelme, & Romojas, 1993; Sanchez, Zamorano, Hernandez, & Alique, 1998). However, since the edible part of cherimoya fruit is characterized by soft segments arranged around its longitudinal axis and the presence of many hard seeds, localized measurements such as those achieved by the penetration test may be highly biased by the orientation of the
segments or the presence of nearby seeds (Peleg, 1979). Most consumers subjectively estimate fruit softness based on its degree of deformation by applying a compression force with the fingers. Compression test on cherimoya fruit stored at different temperatures and RH has been evaluated by Fuster and Prestamo (1980).

Penetration force was high, generally greater than 73 Newton (N) in the preclimacteric stage and then declined to less than 5 N during ripening of soursop fruit (Paul, 1982). The firmness of sugar apple fruit decreased rapidly from 33 N to 1.2 and 1.5 N at 25 and 20 °C, respectively, within 4 to 6 days of storage, whereas the decrease in firmness was gradual at 15 and 10 °C storage. The firmness of ripe fruits was least in fruit stored at 25 and 20 °C as compared to those stored at 15 and 10 °C (Bolivar-Fernandez et al., 2009; Vishnu Prasanna et al., 2000). Cherimoya fruit stored at 10 °C retained its firmness (at approximately 20–27 N) throughout 6 days of storage. The firmness of fruit flesh stored at 15 °C decreased slowly from 27 N to 20 N over 5 days in storage, but declined sharply from 20 N to 5 N on day 6 of storage (Shen et al., 2009).

5.11. Enzymes and proteins

The activities of amylase, polygalacturonase, and cellulase increased during ripening of soursop fruit (Paul et al., 1983). It was established that cherimoya has a large number of constitutive basic and acidic pathogenesis related proteins (PR-proteins) with a wide range of molecular masses, from 14 to 76 kDa (Goni, Sanchez-Ballesta, Merodio, & Escribano, 2009). Increase in expression of the 27 kDa constitutive chitinase and the induction of two new proteins, a 26 kDa chitinase and a 51 kDa 1.3-β-glucanase, were associated with enhanced in vitro hydrolytic and antifungal activity of the acidic protein extract in ripe cherimoya fruit (Goni, Sanchez-Ballesta, Merodio, & Escribano, 2010). Ripening modified the expression of constitutive basic isoenzymes, with a sharp decrease in both relative accumulation and hydrolytic activity. A new basic 33 kDa chitinase was induced in the over ripe fruit, concomitant with accumulation of a basic constitutive 76 kDa 1.3-β-glucanase. At this stage, the basic protein extract modified in vitro growth inhibition of Botrytis cinerea. Short-term high CO$_2$ treatment delayed fruit ripening and maintained a similar distribution of activity and isoenzymatic pattern in both protein fractions to that in the unripe fruit. Therefore, the changes in the pattern of defense proteins and hydrolytic activity in cherimoyas are associated with ripening (Goni et al., 2010). Storage of 'Fino de Jete' cherimoya fruit at 6 °C modified the expression of constitutive isoenzymes and induced the appearance of novel acidic chitinases, ACh1 26 and ACh1 24, at the onset of the storage period, and of a basic chitinase, BCh1 33, after prolonged storage. The induction of this basic isozyme was concomitant with the accumulation of basic constitutive 1.3-β-glucanases. These low temperature-induced chitinases modified the growth inhibition in vitro of Botrytis cinerea. Short-term high CO$_2$ treatment activated a coordinated response of acidic chitinase and 1.3-β-glucanases after prolonged storage at chilling temperature (Goni et al., 2009). Expansins are proteins that have been shown to contribute to fruit softening. Three different full length expansin gene (AcExp1, AcExp2, and AcExp3) cDNAs from ripe cherimoya fruit were isolated and characterized, and their patterns of mRNA expression were investigated in relation to flesh firmness in fruit stored at different temperatures (10 °C, 15 °C, or 20 °C), and in fruit stored at 20 °C and pretreated with propylene (Shen et al., 2009). RNA hybridization revealed that AcExp1 mRNA was detectable throughout 8 days of storage at 10 °C, 15 °C, or 20 °C, and that AcExp2 mRNA was detectable only during the decline in flesh firmness in fruit stored at 15 °C or 20 °C. The accumulation of AcExp3 mRNA coincided with the decline in flesh firmness in fruit stored at 15 °C or 20 °C. Authors concluded that AcExp3, together with AcExp2, may be involved in cherimoya fruit softening.

5.12. Water status

Changes in structure and solute concentration associated with fruit ripening can be analyzed simultaneously, determining fruit water status by differential scanning colorimetry (Goni, Munoz, Ruiz-Cabello, Escribano, & Merodio, 2007). According to the differential scanning colorimetric data, the significant increase in the transverse relocation time values and the loss of flesh firmness during the initial stage of 'Fino de Jete' cherimoya fruit ripening are consistent with the sustainable drop in the un-freezable water weight fraction (Goni et al., 2007). The ripe stage of the fruit was marked by minimum longitudinal relaxation time values and a rapid upsurge in the un-freezable water weight fraction, greatly influenced by the osmotic adjustments prompted by the significant accumulation of soluble sugars, proline and carbohydrates.

6. Postharvest handling and technology

6.1. Fruit ripening

Atemoya fruit had acceptable eating quality up to 4 days after first detectable softening changes, when ripened at 20 °C in ethylene free air or under propylene (Brown et al., 1988). Fruit ripened under ethylene free air had better quality than fruit ripened under propylene. Wills, Poi, Greenfield, and Righley (1984) and Batten (1990) reported ripening periods of 4–5, 5–6 and 8–9 days in atemoya fruits at 24–25, 19–20 and 15–16 °C, respectively. The rate of ripening of 'Balangar' sugar apple fruit was delayed by decreasing storage temperature with more than 90% of the fruits ripened on days 4, 6 and 9 of storage at 25, 20 and 15 °C, respectively (Vishnu Prasanna et al., 2000). Sugar apple fruit reached edible quality at the beginning of the post-climacteric phase, with a postharvest life of no longer than 4 days at 26 °C and 80–90% relative humidity (Bolivar-Fernandez et al., 2009).

Kosiyachinda and Young (1975) found that 'Chaffey' cherimoya harvested late in the season ripened more rapidly and showed a shorter delay between the respiratory climacteric and the rise in internal ethylene production than early season fruit. Nomura et al. (1997) studied the relationship between developmental stage at harvest and the ripening of 'Big Sister' cherimoya and suggested that differences in ripening may be attributed to differences in the heat accumulated during the two months (of the six months of development) corresponding to the resting stage prior to the final enlargement period. According to this hypothesis, a 6–7% difference in the heat accumulated during this period was enough to result in fruit with lower accumulated heat being unable to ripen properly. Better quality and slightly higher sugar content are obtained when the final period of cherimoya fruit growth, prior to harvest, is in a warmer month (Lizana & Reginato, 1990). There was a direct relationship between heat units accumulated during the last month of development and TSS concentration, although differences between mid harvest (November 15) and late harvest (December 10) fruit were not significant (Alique & Zamorano, 2000). Harvest season had no effect on malic and citric acids (Alique et al., 1994; Palma et al., 1993). Perez de Oteiza, Ruiz, Hermoso, Garcia-Tapia, and Farre (1998) did not find clear relationship between harvest date and titratable acidity in 'Fino de Jete' cherimoya.

The number of days required for cherimoya fruit ripening at 15 °C and 20 °C were 9–11 days and 8 days, respectively (Yonemoto, Higuchi, & Kitano, 2002). To determine the optimum storage period, cherimoya fruit of different cultivars were initially stored at 10 °C for 20 days and then ripened at 20 °C. 'Bay Ott' and 'Big Sister' ripened normally, while 'Chaffey', 'El Bumpo' and 'Meriella' turned brown and their quality declined.

6.2. Low temperature storage

The marketing potential of cherimoya is hampered by its high perishability (at 18–20 °C it will ripen in 3–6 days) and susceptibility...
to chilling injury. The optimum temperature for prolonged cold storage of cherimoya, depending on the cultivar, ranges between 8 and 15 °C (Alique et al., 1994; Batten, 1990; Brown & Scott, 1985; Gutierrez, Sola, Pascual, & Vargas, 1994; Ke, Yang, Yu, & Tsi, 1983; Palma et al., 1993). Reports on low temperature storage of annonaceae indicate that the minimum storage temperature varies from 7 to 12 °C depending on cultivar. The ripening period at 20 °C ranged from 5 to 8 days in cherimoyas (Fuster & Prestamo, 1980), 7 days in sugar apple and about 5 days in atemoya (Broughton & Tan, 1979). Wills et al. (1984) reported that of three storage temperatures tested (15, 20 and 25 °C), 20 °C gave the most acceptable fruit for fresh consumption. The safe range of storage temperature for ‘Balanagar’ sugar apple was found to be between 15 and 20 °C, with maximum shelf life at 15 °C. Fruit ripening was observed on days 4, 6 and 9 during storage at 25, 20 and 15 °C, respectively. Pulp color, texture, taste and flavor of ripe fruit held at 25 and 20 °C were superior followed by fruit stored at 15 °C (Vishnu Prasanna et al., 2000).

Storage at 6 °C inhibited the ripening process and caused severe damage in ‘Fino de Jete’ cherimoyas (Montero, Escrivano, De La Plaza, & Merodio, 1995). SDS-PAGE analysis revealed that non-accumulation of some polypeptides related to the ripening process due to storage at 6 °C. Two dimensional electrophoresis confirmed the appearance of specific low-temperature polypeptides observed in freshly harvested fruit persisted during storage, and several acid polypeptides were detected only during the first few days of storage at 6 °C. After a decrease to barely detectable levels during the early phase of cold storage, the proteolytic activity then increased (Montero et al., 1995).

Storage of ‘Fino de Jete’ cherimoyas at 6 °C caused cytoplasmatic acidosis (a decrease of 0.72 pH units) and a notable increase in the amount of inorganic phosphorus in the cytoplasm. Specific activation of phosphoenolpyruvate carboxylase (32.1 μmol min⁻¹ mg⁻¹) was observed in these fruits. In chilled fruits the amount of ADP was maintained at steady state levels and ATP levels increased contrary to ripe fruits, where total nucleotides decreased. Fruit stored at 6 °C exhibited a low respiration rate, but metabolism was not arrested and an increase in TSS contents was also observed (Muñoz, Ruiz-Cabello, Molina-Garcia, Escrivano, & Merodio, 2001).

6.3. Modified (MA) and controlled atmospheres (CA)

De la Plaza, Muñoz-Delgado, and Iglasias (1979) showed that CA (2 kPa O₂ + 10 kPa CO₂ at 9 °C) retarded fruit softening and prolonged the storage life of ‘Fino de Jete’ and ‘Campa’ by 1 week compared to storage in air. This study found that CA had no effect on reducing sugars and titratable acidity in both cultivars, and high CO₂ increased the respiration rate in ‘Fino de Jete’ and ‘Campan’ fruit which had a higher maximum climactic in atmospheres containing 2 kPa O₂ and 10 kPa CO₂ than in air (De La Plaza, 1980). Palma et al. (1993) concluded that ‘Concha Lisa’ cherimoyas can be maintained in 5 kPa O₂ at 10 °C for 43 days and ripen normally after 4 days at room temperature. Fruit of ‘Fino de Jete’ cherimoyas were stored in air and in CA (3 kPa O₂ in combination with 0, 3, and 6 kPa CO₂ at 9 °C (Alique & Oliveira, 1994), and the combination of high CO₂/low O₂ had an additive effect on reducing ethylene production and fruit softening, but did not significantly affect sugars and citric acid. The authors concluded that 3 kPa O₂ in combination with 3 or 6 kPa CO₂ increased the storage life of ‘Fino de Jete’ fruits at 9 °C by 2 weeks over that of fruit stored in air. There were no differences between the 3 and 6 kPa CO₂ (Alique & Oliveira, 1994). ‘Fino de Jete’ fruit held in a combination of 10 kPa O₂ and 10, 15, or 20 kPa CO₂ at 8 °C and 98% RH for 3, 6, or 9 days, ripened later than those held in air (Alique, 1995). Del Cura, Escrivano, Zamorano, and Merodio (1996) treated cherimoya fruit with 20 kPa CO₂ for 9 days and observed unacceptable quality due to bitterness. Atmosphere with 20 kPa CO₂ for 3 days delayed fruit softening, retarded the accumulation of polygalacturonase-related protein, and maintained chlorophyll content of the peel (Yahia & Singh, 2009).

Several mechanical parameters obtained by means of compression and penetration tests, and changes in cherimoya fruit during storage in air and CA (3 kPa O₂ + 0 kPa CO₂ or 3 kPa O₂ + 3 kPa CO₂) were analyzed by Zamorano, Alique, and Canet (1999). A gradient of softening was found among the equatorial and the apical areas of the flesh during CA storage, as assessed by localized penetration tests. The combination of low O₂/elevated CO₂ (3 kPa O₂ + 3 kPa CO₂) increased this gradient and had a greater inhibiting effect on skin softening than low O₂. The prevention of softening by CA was stronger in the less mature tissues (equatorial and outer areas) than in more mature tissues (apical and inner areas around the longitudinal axis). CA delayed or inhibited changes in fruit quality observed during air storage (Zamorano et al., 1999). High CO₂ levels (20 kPa CO₂ and 20 kPa O₂) were found to provoke the coordinated accumulation of a chitinase and 1,3-β-glucanase in cherimoya fruit. Chitinase activity was higher in treated than in untreated fruit. At the end of CO₂ treatment (3 days), total polyamine and γ-aminobutyric acid content and uptake of O₂ were observed to be higher in treated compared to untreated fruit, but the accumulation of these compounds decreased when the fruit was transferred to air. Since this treatment effectively retains fruit quality (Escribano, Del Cura, Muñoz, & Merodio, 1997), CO₂ levels may have a direct effect on the activation of specific responses that enable cherimoya fruit to overcome chilling temperature (Merodio, Muñoz, Del Cura, Buitrago, & Escrivano, 1998).

Short CA treatments, involving exposure to 10 kPa O₂ combined with 10, 15, and 20 kPa CO₂, have been tried on a selection of biochemical parameters and related enzymatic activities of cherimoya fruit stored for 9 days (Sanchez, Zamorano, Hernandez, et al., 1998). Assis, Maldonado, Muñoz, Escrivano, and Merodio (2001) kept ‘Fino de Jete’ cherimoya at 20 °C in air or in 20 kPa CO₂ for 3 days before transfer to air. Total phenols remained constant while a rapid decline in lignin content and polyphenol ammonia liase (PAL) activity was observed during 2 days at 20 °C. The maximum ethylene production was observed 2 days later. At the end of CO₂ treatment, ethylene production was inhibited and PAL activity was similar to that found in air-treated fruit. The CO₂ treatment inhibited flesh softening and maintained lignin at levels found in freshly harvested fruit and also improved the color of the fruit (Assis et al., 2001).

At ripening temperature (20 °C), 20 kPa CO₂ inhibited ethylene production, but 1-aminocyclopropane-1-carboxylate (ACC) oxidase activity was similar to that in control fruit of ‘Fino de Jete’ cherimoya (Muñoz, Aguado, Ortega, Escrivano, & Merodio, 1999). CO₂ treatment led to a decline in putrescine (Put) and a major accumulation of spermidine (Spd) and spermine (Spm) without any effect on arginine decarboxylase (ADC) activity. The authors confirmed the preferential transformation of Put to Spd and Spm in CO₂ treated fruit, while at chilling temperatures (6 °C), the increase in ACC oxidase activity was inhibited and the Vmax of ADC increased. A combination of chilling temperature storage and high CO₂ level led to suppression of ethylene production while ACC oxidase activity remained unchanged. Fruit held at these conditions had higher polyamine titres than the untreated control. In CO₂ treated fruit the absence of autocatalytic or basal ethylene production depending on temperature may be due to deviation of S-adenosylmethionine (SAM) pool towards polyamine synthesis, primarily Spd and Spm (Muñoz et al., 1999). Cherimoya fruit exhibited active nitrogen metabolism mainly under high CO₂ (20 kPa) levels (Merodio et al., 1998), and the high nitrogen re-assimilation was correlated with a high PAL activity. On the contrary, fruit showing low PAL activity accumulated high levels of endogenous ammonia (Maldonado, Molina-Garcia, Sanchez-Ballesta, Escrivano, & Merodio, 2002). Specifically, this metabolic situation occurred in fruit during the first days of storage at chilling temperature (6 °C) (Maldonado et al., 2002). High CO₂ (20 kPa) treatment improved tolerance to prolonged storage at chilling temperature and was found
closely linked to the maintenance of fruit energy metabolism, pH stability, and the promotion of synthesis of defense compounds that prevented or repaired damage caused by chilling temperature (Maldonado, Sanchez-Ballesta, Alique, Escobari, & Merodio, 2004). Annona fruit has been considered as a good model to analyze the phenylalanine-cinnamate pathway and the regulation of PAL (Asis et al., 2001; Maldonado, Goni, Escobari, & Merodio, 2007; Maldonado et al., 2002, 2004; Merodio et al., 1998).

6.4. Effect of 1-methylocyclopropene (1-MCP)

In order to retard ripening of sugar apple, fruits were treated with 1-MCP at concentrations of 0, 30, 90, 270 or 810 nL L\(^{-1}\) for 12 h at 25 °C and then stored at 25 °C for 4 days (Benassi, Correa, Kluge, & Jacomino, 2003). There were no differences among treatments with regard to TSS content. However, fruit treated with 810 nL L\(^{-1}\) of 1-MCP showed higher firmness than fruit treated with lower concentrations. ‘African Pride’ sugar apple fruits were gassed with 25 μL L\(^{-1}\) 1-MCP for 14 h at 20 °C, followed by treatment with 100 μL L\(^{-1}\) ethylene for 24 h, and then ripened at 20 °C (Hofman, Jobin-Décor, Meiburg, Macnish, & Joyce, 2001). Treatment with ethylene alone reduced the days to ripe (DTR) by 42% compared with untreated fruit. 1-MCP increased the DTR by 58% and 167% compared with untreated and ethylene treated fruit, respectively. 1-MCP treated fruit had a higher percentage of black tips compared with untreated fruit or to those treated with ethylene alone. Ethylene and 1-MCP treatments increased the severity of gray flesh. 1-MCP treated fruit had more severe black discoloration and core rot than those treated with lower concentrations.

Delay in ‘African Pride’ cherimoya fruit softening by 1-MCP in relation to the expression of xyloglucan endotransglycosylases (XET) and expansins (EXP) genes was investigated by Li et al. (2009). Application of 1-MCP greatly delayed and inhibited ethylene production and softening of fruit during storage at 20 °C. Three full length XET cDNAs (AcXET1, AcXET2 and AcXET3) or expansins cDNA (AcEXP1, AcEXP2 and AcEXP3) exhibited different expression patterns during fruit softening while mRNAs of AcXET2, AcEXP1 and AcEXP3 significantly accumulated on day 3 and mRNAs of AcXET1 or AcEXP2 accumulated on day 5 or day 6. Differential expression of AcXETs and AcEXP5 is associated with fruit softening of cherimoya and application of 1-MCP retarded or suppressed the expression of AcXETs or AcEXP5, which may be attributed, at least partially, to 1-MCP delayed fruit softening (Li et al., 2009).

6.5. Waxing

Coating cherimoya fruit with wax containing caranauba wax, morpholine fatty acid salt, selloam gum lac, microcrystalline wax, sodium polyphosphate, and orange oil, decreased respiration and ethylene production of the fruit, and extended the shelf life by 5 days, with less weight loss and minimal browning (Yonemoto et al., 2002).

6.6. Effect of calcium

According to Lima (2000), sugar apple fruit treated with CaCl\(_2\) (6%) and stored at 16 °C had reduced weight loss and respiration rates, less peroxidase activity, and higher firmness, and the biochemical processes of ripening were delayed. Fruit of ‘Gefner’ atemoya were immersed in 6% CaCl\(_2\) solution at 20 and 40 °C for 20 min followed by storage at room temperature (Torres, Silva, Guaglianoni, & Neves, 2009). Treatment at 40 °C preserved eatable conditions for 6 days. The authors suggested that CaCl\(_2\) dipping had a positive effect on flesh browning, which was reduced, while heat treatment showed a synergic effect, which could be reflected broadly with a fall in polyphenol oxidase (PPO) activity (Torres et al., 2009).

6.7. Effect of salicylic acid

Physiological and biochemical responses in harvested sugar apple fruit to salicylic acid (SA) at 0.4, 0.8 and 1.2 mM L\(^{-1}\) were investigated during storage (Mo et al., 2008). SA treatments lowered respiration, increased activities of antioxidant enzymes such as superoxide dismutase (SOD), peroxidase (POD), catalase (CAT) and ascorbate peroxidase (APX), decreased lipoygenase (LOX) activity and correspondingly lowered malondialdehyde (MDA) contents in treated fruits as compared to the control. Moreover, production of superoxide free radical (O\(^2\)\_) and ethylene was significantly decreased in the treated fruit. TSS, total sugar content, softness and decay rate were significantly lowered in treated fruit, and in turn a delay in the fruit ripening process was achieved after 10 days of storage. The authors concluded that SA has positive effects in maintaining membrane integrity and in delaying fruit ripening process, which results in improved storability of sugar apple (Mo et al., 2008).

6.8. Packaging

Individual film sealing of atemoya cv. PR3 extended their shelf life (Yamashita, Miglioranza, Miranda, & Souza, 2002). At 15 °C, non-wrapped atemoya fruit had a shelf life of 13 days compared to 17 days of those wrapped with PD-955 (copolymer). Low density polyethylene (LDPE) film was found to be inadequate to package atemoya. Fruit should be unwrapped before ripening at room temperature to avoid off flavor development.

7. Postharvest disorders

7.1. Browning

Fruits are commonly susceptible to enzymatic browning catalyzed by PPO affecting its sensory and nutritional qualities. Lima, Barbosa Guerra, Sucupira Maciel, and Souza Livera (1994) studied PPO activity in soursop fruit as a function of pH and phenolic concentration during maturation, and observed that the pH of optimum activity was 7.0 for fully ripe and 7.5 for immature, mature and ripe fruits. The effect of pH (3 to 8.8), temperature (20 to 60 °C) and chemical inhibitors (ascorbic acid, EDTA and SO\(_2\)) at several concentrations on soursop fruit PPO activity was studied by Bora, Holschuh, and da Silva Vasconcelos (2004). PPO of the soursop fruit exhibited optimum pH and temperature of 7.5 and 32 °C, respectively. Its behavior with respect to inhibition in the partially purified enzyme extract was different than in the fruit pulp. To achieve a similar degree of PPO inhibition at the physiological pH of the pulp, higher SO\(_2\) concentrations as well as heating at 80 °C were required for the pulp pH than for partially purified enzyme extract. The conditions for enzyme extract are not sufficient to avoid browning in food products (Bora et al., 2004).

Cherimoya fruit is also prone to browning (Martinez, Serrano, Pretel, Amoros, et al., 1993), which is considered one of the most important oxidative reactions leading to loss of sensory and nutritional quality (Amiot, Fleuriot, Cheynier, & Nicolas, 1997). Enzymatic browning of Spanish cherimoya has been studied by various investigators (Demedina, Plata, Martinez-Cayuela, Faus, & Gil, 1986; Martinez-Cayuela, Plata, Sanchez de Medina, Gil, & Faus, 1989; Martinez-Cayuela, Sanchez de Medina, Faus, & Gill, 1988; Plata, Demedina, Martinez-Cayuela, Faus, & Gil, 1987; Martinez-Cayuela, Faus & Gill, 1988) who purified PPO and characterized its monophenolase and diphenolase activities. The browning of an Italian cherimoya has also been analyzed by Mastrocola, Manzocco, and Poiana (1998). Martinez-Cayuela, Plata, Faus, and Gil (1988) studying partially purified cherimoya PPO found that phenolic compounds associated to carboxylic group and benzene nucleus can inhibit PPO activity. Some endogenous reductants can remove the quinines generated by PPO, which makes the detection of its enzymatic activity
difficult. Prieto et al. (2007) worked on the cloning of a full length cDNA, an analysis of its properties in the deduced amino sequence and linkage of its mRNA levels with enzyme activity in mature and ripe 'Concha Lisa' cherimoya fruits after wounding. They found one gene different at the nucleotide level when compared with previously reported genes, but a well conserved protein in functional and in structural terms. Cherimoya PPO gene (Ac-ppo, GenBank DQ990911) showed to be present apparently in one copy of the genome, and its transcripts could be significantly detected in leaves and less abundantly in flowers and fruits. Analysis of wounded matured and ripened fruit revealed an inductive behavior for mRNA levels in the flesh of mature cherimoya after 16 h. A lack of correlation between PPO mRNA level and PPO activity was observed. This is due to the presence of monophenolic substrates including a lag period, enzyme inhibitors and/or diphenolic substrates causing inactivation, and proenzyme or latent isoforms of PPO (Prieto et al., 2007).

Browning development is the most important factor limiting the quality of fresh-cut cherimoya. Campos-Vargas et al. (2008) studied the effectiveness of treatment with l-cysteine (0.125, 0.25 and 0.5%) in fresh cut cherimoya harvested on two occasions (October and November) and stored for 6 and 12 days at 0 °C. l-cysteine at 0.5% was somewhat effective in reducing browning development, without affecting other quality attributes. PPO activity was not different in mature and ripe fruit in both harvest times, but fruit picked in November presented lower PPO activity and total phenolic content of l-cysteine-treated fruit did not show consistent differences with untreated fruit after 6 or 12 days at 0 °C. PPO activity was higher in the outer part of the cherimoya flesh compared to the middle or inner sector.

7.2. Fruit splitting

Atemoya fruit splitting, which occurs frequently, reduces marketable yield and quality and increases disease attack (George et al., 1987). Splitting during atemoya fruit ripening first appears around the peduncle and radiates out from the fruit base. It can occur before and after harvest and the intensity varies with the cultivar. Early in the season fruit with high TSS are very prone to splitting (Paull, 1996). It commonly starts at the respiratory peak when ethylene production is increasing (Paull, 1996). The initiation of splitting coincides with the decline of about one fifth of the starch level in the fruit, total sugars and titratable acidity being very close to their maximum, and near maximum of flavor production (Wills et al., 1984). Atemoya splitting was suggested to be due to the osmotic and subsequent turbid言 changes related to production of neutral sugars during ripening led to the movement of water from the skin and receptacle to the flesh (Paull, 1996). The effect of water movement was compounded with weight loss during ripening. In addition, the receptacle had higher dry matter content, but also increased in diameter possibly imposing increased stress on the flesh and skin. Heating the fruit to 47.5 °C, with increasing levels of humidity increased split number and width. Shrink wrapped fruits had fewer and narrower splits (Paull, 1996).

7.3. Chilling injury (CI)

Cherimoya fruit is highly susceptible to CI (Gutierrez, Sola, Pascual, Rodriguez-Garcia, & Vargas, 1992). Sugar apple fruit develops CI within 5 days at 4 °C (Broughton & Tan, 1979), while other Annona spp. such as A. cherimola var. Concha Lisa seems to be more resistant. Depending on the area of production and the month of harvest, 10 °C is the minimum storage temperature for local cultivars allowing ripening of cherimoya without impairing the normal organoleptic characteristics of the ripened fruit, and without the development of CI related symptoms (Gutierrez et al., 1992; Lahoz, Gutierrez, Martinez-Cayuela, Pascual, & Vargas, 1990). In cherimoya, CI was observed at 5 °C with the fruit becoming hard and black (Fuster & Prestamo, 1980). Sevillano, Mar Sola, and Vargas (2010) investigated the induction of small heat shock proteins (sHSPs) in the mesocarp of cherimoya fruit. Heating the fruit at 55 °C during 5 h alleviated CI symptoms when the fruit was stored at 4 °C. The thermal stress induces proteins recognized by antibodies against sHSPs of different classes from other plant species. This induction was proportional to the temperature in the experimental range of 46–50 °C.

8. Conclusions

Annona fruits are climacteric, characterized by high levels of ethylene (up to 100–300 μL kg⁻¹ h⁻¹, depending on cultivar) during ripening. Annona fruits are relatively soft fruits and need to be handled with care to minimize bruising. Cherimoya, atemoya and sweetsop have high concentrations of sugars (14–15% when ripe) and moderate acidity (0.4–0.7% when ripe), and are good sources of vitamin C (45–60 mg/100 g) and potassium (250–500 mg/100 g edible portion). In some cultivars fruit splitting occurs with advanced ripening stages and increased ethylene production rates. It has been suggested that, as the sugar and acidity continue to increase, ethylene production increases, promoting fruit softening and causing fruit splitting. The increase in receptacle diameter increased the stress on the flesh and skin leading to fruit splitting. Important pathological disorders of annona fruits include anthracnose, which appears as dark lesions and may produce pink spore-masses under high humidity conditions, black canker which appears as purple spots on the fruit, becoming hard and cracked followed by development of black bodies containing spores, and botryodiplodia which appears as white patches and may produce pink spore-masses under high humidity conditions. Control of postharvest diseases includes good orchard sanitation to minimize sources of fungal spores, preharvest application of fungicides, careful handling to reduce physical damage, prompt cooling to 10 °C, and subsequent maintenance of optimum temperature and relative humidity during marketing. Maturity and harvesting indices of cherimoya, atemoya, sweetsop, and custard apple include change in skin color from dark-green to light-green or greenish-yellow, appearance of cream color between segments on the skin and increased surface smoothness of the separate fruit carpels. Quality indices of these fruits include fruit size, color, absence of defects and decay, and firmness. Optimum handling temperature is 8–12 °C depending on cultivar, ripeness stage, and duration, all at 90–95% RH. Annona fruits are sensitive to temperatures below 8–12 °C, depending on cultivar and ripeness stage, resulting in chilling injury, causing darkening and hardening of skin, pitting, failure to develop full flavor, and mealy flesh. Exposure to ethylene (100 ppm for 1–2 days) accelerates ripening of mature-green cherimoya and other annona fruits; they can ripen in about 5 days if kept at 15 °C for 20 °C. Ethylene removal can be helpful in retarding ripening of mature-green fruits. MA/CA can delay ripening, lower respiration and ethylene production rates, and firmness retention, and optimum atmosphere is 3.5 kPa O₂ and 5–10 kPa CO₂. Cherimoyas can be kept for up to 6 weeks at 10 °C in 5 kPa O₂, and can then be ripened with good flavor at 20 °C. However, exposure to <1 kPa O₂ and/or >15 kPa CO₂ can result in development of off-flavors and uneven ripening.

References


