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Soursop (*Annona muricata* L.)

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Abstract: Soursop is a very perishable fruit. At room temperature, it has a shelf life limited to five days when it has been harvested at physiological maturity. Research into this fruit has been limited to date but its attractive flavor favors its commercialization in different regions. Identification of the correct harvest time and the use of postharvest technologies such as refrigeration, coatings and modified atmospheres, etc., can extend the shelf life of soursop fruit. The impact of orchard management on fruit quality is also considered.

Key words: annonaceae, maturation, postharvest conservation, quality.

18.1 Introduction

Soursop fruit is an exotic commodity in most markets, therefore the quantity harvested comprises only a small percentage of total world fruit production. Cultivation is restricted to a few countries where consumption is more widespread. However, the distinctive and characteristic flavor of soursop gives it the potential to conquer new markets. This is dependent, though, on the development and employment of efficient handling and postharvest conservation technologies: without these, sale of the fruit is limited to regions near the areas of cultivation. In most of the producing countries even the traditional markets for fresh soursop are not supplied with the required regularity due to the fruit's high perishability and short postharvest conservation period. Both have been responsible for the high rates of loss of soursop fruit.

Notwithstanding the postharvest conservation issues, there has been very little research into soursop fruit to date. The studies have generally characterized the maturation of the fruit through changes in peel color and the levels of sugars, organic acids and phenolic compounds found in the pulp (Paull *et al.*, 1983; Aziz and Yusof, 1994). In addition, studies carried out by Lima *et al.* (2006) present

information on the main changes related to the softening of soursop fruit due to physical, chemical and biochemical factors during postharvest ripening at room temperature.

In order to elucidate the metabolism of soursop fruit, more information than is currently available is required for further studies on conservation techniques suitable to the quality standards of different markets. Regarding postharvest technologies, some studies are at present being carried out and include the use of cooling, modified atmosphere packaging (MAP), coatings and ethylene inhibitors.

18.1.1 Origin, botany, morphology and structure

Soursop (*Annona muricata* L.) is a species natural to the tropical Americas, most commonly found on the Caribbean islands (Zayas, 1966). It belongs to the Annonaceae family and like other fruit of the genus *Annona* is a syncarp formed by the coalescence of pistils and receptacles in a large pulpy structure. It is, therefore, a compound fruit formed by a cluster of berries, whose individual carpel components remain in the peel during the entire development in the form of spurs or pulpy spines, which are curved and short (Bueso, 1980; Worrell *et al.*, 1994). Each unit resulting from the fertilization of an ovary is called a fruitlet.

Irregular (i.e. atypical) fruits may appear (Bueso, 1980), due to fertilization and fruiting failure. Such fertilization issues are mostly due to phenomena such as heterostyly (Ramos, 1999) and protogynous dichogamy (Worrell *et al.*, 1994; Ramos, 1999). However, in commercial plantations where hand pollination is a regular procedure, the fruits are ovoid or cordate, measuring 15 to 30 cm in length and 10 to 20 cm in width, with an average weight of 4.5 kg. The peel is thin and dark green in color (see Plate XXXIII(A) in the colour section between pages 238 and 239). The mesocarp contains seeds of shiny dark brown color, which measure about 2 cm in length and 1 cm in width. The pulp, which consists of fibrous, juicy segments or buds (the fruitlet) around an oblong receptacle, is white (Fig. 18.1) and has an acid taste and characteristic flavor (Zayas, 1966; Bueso, 1980; Falcão *et al.*, 1982). When the fruit is ripe, the fruitlets separate easily from the total mass.

18.1.2 Worldwide importance

The world production of soursop fruit is concentrated in a few South American countries, mainly Venezuela, Brazil and Colombia. In Venezuela, the main producer of the fruit in South America, the states with largest production are Zulia, Mérida and Trujillo (Ministerio del Trabajo y Seguridad Social, 1995). However, up-to-date official statistics on production and commercialization of the fruit are not available even in these states (Lima *et al.*, 2002b). In Colombia, fresh soursop fruit is said to be available throughout the year. The country is a large consumer of the fruit, even importing it from Venezuela in the form of frozen pulp. Beside the South American countries, soursop occupies a prominent position in the fruit markets of Central America and the Caribbean, and it also stands out on the Asian continent (Universidade Federal de Uberlândia, 2010). In Central

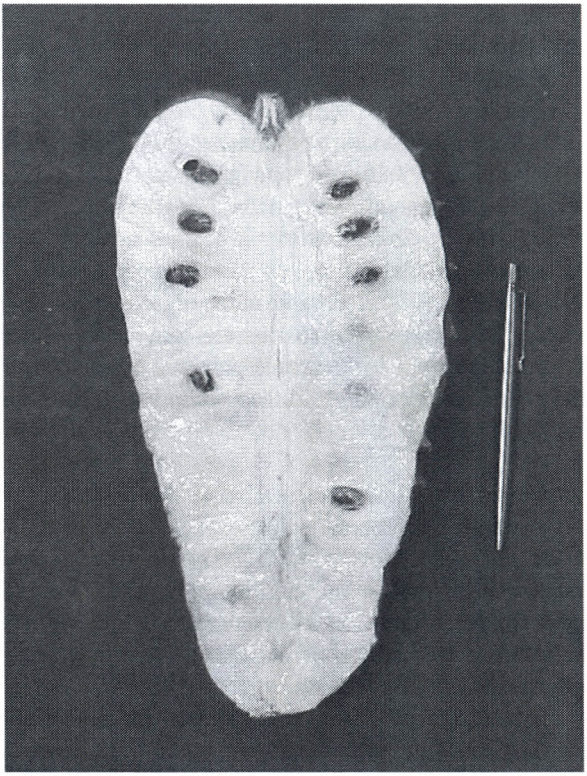

Fig. 18.1 Pulp aspect of soursop fruit. Photo: Maria Auxiliadora Coêlho de Lima.

America, Mexico is an important producer and consumer of soursop fruit. The country exports the fruit regularly throughout the year and has recorded an increase in yearly mean values in the market for the fresh fruit over the last five years (Panorámica, 2010).

In general terms, one of the main problems with the commercialization of soursop fruit is the transport, which is done by truck and without proper packaging, resulting in elevated losses when the product reaches the retail market (Calzavara and Muller, 1987; Moura, 1988).

Although in Brazil soursop fruit has been mentioned in literature since the beginning of the 20th century (Correa, 1984), its commercial importance for the domestic and export markets is still very low, and the interest in exploring it commercially is quite recent (Calzavara and Muller, 1987). In Brazil, soursop production is concentrated in the north and northeast, from where the fruit is distributed to other regions of the country. The largest product of commercial production of soursop is the frozen pulp, which supplies the juice and ice cream industries. Over the last few years, the area of Brazilian land used for soursop

cultivation has been reduced. The main reason for this is the increase in production costs, due to the large incidence of pests such as stem borer and fruit borer.

On the other hand, even though secure and objective statistical data may not be available, the demand for soursop pulp is growing in the Brazilian as well as in the European market. Regarding the external market, there is a demand for soursop pulp both in the Middle East and in Europe (Germany and Spain) (Secretaria de Agricultura do Estado da Bahia, 2010). However, the exportation of pulp and other soursop fruit products has been restricted to a few countries, such as Mexico, Puerto Rico, Venezuela and Costa Rica. For years, soursop pulp has been served in Mexican restaurants in New York and other big cities in the United States, soursop pulp concentrates have been commercialized in Venezuela, while nectar is sold in several countries. In Costa Rica, soursop pulp and frozen fruit concentrates have been traditionally sold for several years (Morton, 1987).

18.1.3 Culinary uses, nutritional value and health benefits

Soursop fruit is suitable for processing because of its high sugar content and delicate flavor (George, 1984; Mororó *et al.*, 1997). However, there are limitations on the industrial processing of soursop fruit. Soursop fruit is sold as fresh or frozen pulp, strained soursop juice, and frozen concentrates, which have been preserved as various juice blends, ice creams, sherbets, nectars, syrups, shakes, jams, jellies, preserves, yoghurts and ice creams (Bueso, 1980; Morton, 1987; Umme *et al.*, 1999; Gratao *et al.*, 2007). It is also a raw material for powders, fruit bars and flakes (Umme *et al.*, 2001). It can be made into a fruit jelly with the addition of gelatin or used in the preparation of beverages, sherbets, ice creams and syrups (Bueso, 1980; Badrie and Schauss, 2009). The immature fruits with soft seeds have been cooked as vegetables. Seeds can be roasted or fried (GetJamaica.Com, 2008).

The white edible pulp of soursop fruit contains 80–85% water, 1% protein, 18% carbohydrate, 0.70–3.43% titratable acidity and 13.5–19% soluble solids, with about 1.0% fiber content and vitamins B1, B2, and C (Wenkam and Miller, 1965; Paul *et al.*, 1983; Castro *et al.*, 1984; Rice *et al.*, 1991; Filgueiras *et al.*, 2002; Onimawo, 2002; Lima *et al.*, 2003a, 2003b, 2004; Lako *et al.*, 2007). The reducing sugars, glucose and fructose, were 81.9–93.6% of the total sugar content. Using gas-liquid chromatography, the fructose, D-glucose and sucrose contents of soursop pulp were found to be 1.80, 2.27 and 6.57% respectively, giving a total sugar content of 10.48% (Chan Junior and Lee, 1975). According to Filgueiras *et al.* (2002), the medium pulp yield is approximately 80%.

Eleven free amino acids were identified using paper chromatography and four other unidentified ninhydrin-positive components were detected. The most abundant free amino acids were proline and γ-aminobutyric acid (Ventura and Hollanda-Lima, 1961). Other amino acids detected, in order of the amount present, were glutamic acid, aspartic acid, serine glycine, alanine, citrulline, cysteine (or cystine), arginine and lysine (Paull, 1998).

Kuskoski *et al.* (2006) examined the total polyphenol index and the antioxidant activity of soursop pulp, finding values of 84.3 ± 5.8 mg.100 g^{-1} and 2.88 ± 0.2 μmol

Trolox equivalent.g^{-1} fresh matter after 30 minutes. Lako *et al.* (2007) evaluated fresh fruit and found values of 72 mg.100 g^{-1} Trolox equivalent for the total antioxidant capacity, and 42 mg.100 g^{-1} equivalent in gallic acid for the total polyphenol content, supplying an estimate of losses occurring during processing. The authors also characterized the content of some flavonols in soursop fruit. They observed a myricetin content of 3 mg.100 g^{-1}, less than 1 mg.100 g^{-1} of fisetin, 2 mg.100 g^{-1} of morin, 2 mg.100 g^{-1} of quercetin, 2 mg.100 g^{-1} of kaempferol and less than 1 mg.100 g^{-1} of isorhamnetin. The quantification of these compounds helps to determine which particular properties of soursop fruit are instrumental in preventing certain diseases related to the presence of free radicals in the organism. For example, *A. muricata* is an abundant fruit tree that yields acetogenins. Some of these acetogenins, including bullatacin, have the potency of taxol against L1210 murine leukemia. They work by inhibiting adenosine triphosphate (ATP) production (Badrie and Schauss, 2009).

18.2 Fruit growth and ripening

Understanding the postharvest physiology of soursop fruit is necessary for the establishment of handling procedures and the recognition of ideal packaging conditions. It is also useful when selecting materials and techniques to protect the fruit from external factors which may accelerate deterioration. When studying postharvest physiology, it is assumed that physiological changes which occur after harvest are affected by agricultural practices and environmental conditions during cultivation, as well as by the fruit's own metabolism during its growth, development and maturation.

18.2.1 Fruit growth, development and maturation

According to Worrell *et al.* (1994) and Livera and Guerra (1996), the fruit's growth pattern is of the double sigmoid type, presenting three characteristic stages. The initial stage of rapid growth begins immediately after the end of the quiescence (the period of rest after fertilization of the blossom, which is characterized by the darkening of the upper part of the carpel). At the end of this stage, the soursop fruit has already reached half of its final size and shoulders have begun to develop around the point of pedicel attachment. The following stage (*lag* phase) is characterized by relatively slow growth and precedes the final stage of rapid growth. During the latter the fruit reaches maturity and its maximum size (Worrell *et al.*, 1994).

Under Brazilian climate conditions, soursop fruit reaches complete maturity between four and six months after pollination, depending on the time of year (São-José, 1997). In the northeast of Brazil, studies have shown that the fruit reaches its physiological maturity around 90 days after the beginning of the quiescence period (Mosca, 1996).

Maturation constitutes the final stage of fruit development, during which the cells reach their maximum size and characteristic composition (Kays, 1997). For soursop

fruit, the main changes associated with maturation are: greater separation between and loss of firmness of the spurs; loss of firmness of the fruit surface, which is noticeable to the touch. The divisions between the loculi protrude, showing the fruitlets; and the seeds turn a shining dark brown color. For most of the phenotypes, the shine of the peel also increases and its color changes from dark green to a lighter tonality, as shown in Plate XXXIII(B) in the colour section (Zayas, 1966; Worrell *et al.*, 1994; Borrero *et al.*, 1995; Livera and Guerra, 1996; São-José, 1997; Salgado *et al.*, 1998; Filgueiras *et al.*, 2002). However, the time from fruit formation to physiological maturity, which is taken as a secure indication for harvesting for certain crops, is not an appropriate one for soursop fruit (Borrero *et al.*, 1995; Livera and Guerra, 1996). The duration of the second growth stage can differ, resulting in variations in the maturation stages between fruits of the same age (Livera and Guerra, 1996).

A series of mostly independent changes characteristically occur during ripening, which includes the final stages of maturation and the beginning of the senescence. Emphasis can be placed on those which result in alteration of flavor, color and firmness (Kays, 1997; Wills *et al.*, 2007).

In soursop fruit, the modifications related to fruit ripening occur over a very short period (Paull, 1982; Aziz and Yusof, 1994; Mosca *et al.*, 1997), reflecting an elevated metabolic activity. Studies carried out by Paull (1982) and Lima *et al.* (2003a) show that fruits which are harvested at physiological maturity and kept at room temperature ripen within five days.

Until the soursop fruit is completely ripe, it goes through changes, for example in its respiratory activity, ethylene production, contents of total soluble solids, sugars and starch, in volatile compounds and in total titratable acidity (Paull, 1982, 1990; Paull *et al.*, 1983; Bruinsma and Paull, 1984; Castro *et al.*, 1984; Aziz and Yusof, 1994; Worrell *et al.*, 1994; Borrero *et al.*, 1995; Mosca *et al.*, 1997).

18.2.2 Respiration, ethylene production and ripening

Fruits of the family Annonaceae, such as soursop, are classified as climacteric for presenting an increase in their respiratory activity and ethylene production during maturation. These fruits ripen after harvest (Alves *et al.*, 1997).

However, the respiratory activity of soursop fruit during ripening is different to that of most other climacteric species. Biale and Barcus (1970) characterized soursop fruit as having a diffuse climacteric pattern with more than one peak. The same was observed for other species of the genus *Annona* and was attributed to the fact that the fruit is formed by many aggregate ovaries. The development and further ripening of each fruitlet seemed, therefore, to be variable within the pulp of the organ as a whole.

Other authors have developed research on the respiratory activity of soursop fruit (Paull, 1982, 1990; Paull *et al.*, 1983; Bruinsma and Paull, 1984; Worrell *et al.*, 1994; Lima *et al.*, 2003b). Most of these studies were carried out on the intact fruit. However, Bruinsma and Paull (1984) studied the respiratory activity in both intact fruits and soursop tissue discs. The authors observed that the diffuse climacteric pattern occurred in the discs as well. Given this fact, they concluded that the initial

respiratory increase was caused by the elevation in mitochondrial respiration due to an increase in the supply of induced carboxylate substrates, probably induced by the separation of the fruit from the tree. This contradicts the assumption that the existence of two respiratory peaks reflects the changes in tissues that are in different physiological stages (Biale and Barcus, 1970; Paull, 1982).

When researching the respiratory behavior of 'Morada' soursop fruit, Lima *et al.* (2003b) observed that CO_2 production was stable at about 70 mg $CO_2.kg^{-1}.h^{-1}$ until the second day after harvesting at physiological maturity (Fig. 18.2). From the second day a rapid increase began, resulting in the first respiratory peak and corresponding to a production of 197.60 mg $CO_2.kg^{-1}.h^{-1}$. Other authors reported the occurrence of the first respiratory peak from the second to the fourth day after harvesting, with values varying from 50 to 170 mg $CO_2.kg^{-1}.h^{-1}$ (Biale and Barcus, 1970; Paull, 1982; Bruinsma and Paull, 1984; Worrell *et al.*, 1994).

After the first climacteric peak, few variations in the respiratory activity of soursop fruit occurred, characterizing a *lag* phase (Worrell *et al.*, 1994; Lima *et al.*, 2003b). At the end of this phase, the next respiratory increase resulted in the climacteric peak itself, which was observed between the fourth and the fifth day after harvesting and reached 298.82 mg $CO_2.kg^{-1}.h^{-1}$ in the study by Lima *et al.* (2003b). The occurrence of this peak could be observed from the fourth to the sixth day after harvesting, with values ranging from 130 to 305 mg $CO_2.kg^{-1}.h^{-1}$ (Biale and Barcus, 1970; Paull, 1982; Bruinsma and Paull, 1984; Worrell *et al.*, 1994).

Differences in the respiratory rates verified in both peaks can be attributed to the maturation phases used in each study, as well as the genetic material, the methods employed, and the conditions that the fruits were submitted to, especially temperature.

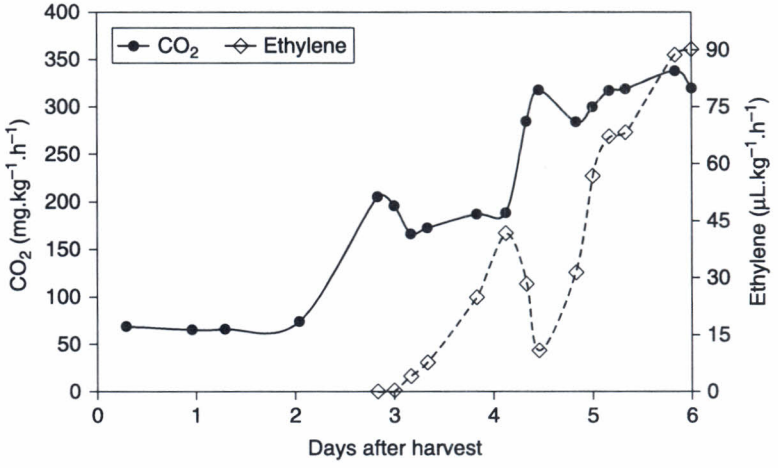

Fig. 18.2 Respiratory behavior and ethylene production of 'Morada' soursop fruit harvested at physiological maturity and stored under room temperature. Source: Lima *et al.* (2003b).

Typical characteristics of ripening such as changes in color, firmness and development of flavor and aroma are associated with the climacterium (Biale and Barcus, 1970). However, some of these depend on the production of the phytohormone ethylene (Jeffrey *et al.*, 1984; Ayub *et al.*, 1996).

Ethylene production starts with methionine which, through successive reactions, forms S-Adenosyl methionine and 1-aminocyclopropane-1-carboxilic acid (ACC). Under the action of ACC oxidase the latter produces ethylene (C_2H_4), CO_2 and cyanide (Dean and Mattoo, 1991; Kende, 1993; Kays, 1997). The synthesized ethylene connects to sites in the cell membranes that have characteristic receptors. They are, therefore, saturable, present a high affinity and specificity for ethylene, can suffer denaturation and are liable to competitive inhibition by structurally similar molecules (Paliyath and Droillard, 1992). From this viewpoint, some work has been carried out with the purpose of delaying the ripening or the senescence of some organs. Studies of this nature brought about the identification of the gene ETR1 which codifies for a protein that is a receptor of ethylene (Bleecker and Schaller, 1996).

In climacteric fruits, the increase in ethylene production during ripening may occur before, during or after the climateric peak. In those fruits the biosynthesis of ethylene is called autocatalytic (Tucker, 1993). Experiment results have shown that the ethylene production in soursop fruit is not detectable until two days after harvesting (Bruinsma and Paull, 1984). Lima *et al.* (2003b) started to detect ethylene production on the third day after harvesting, on the occasion of the first respiratory peak (Fig. 18.2). From that point on, the synthesis increases until reaching the ethylene peak, which is followed by a decrease (Paull, 1982; Bruinsma and Paull, 1984; Worrell *et al.*, 1994). Values from 40 to 350 $\mu L.kg^{-1}.h^{-1}$ have been observed for this peak (Paull, 1982; Bruinsma and Paull, 1984; Worrell *et al.*, 1994; Lima *et al.*, 2003b).

In the studies carried out by Lima *et al.* (2003b), the ethylene peak occurred on the fourth day, matching with the respiratory increase which results in the climacteric peak. This result reinforces the idea that the climacteric increase is a response to ethylene (Dean and Matoo, 1991).

The recognition of the moment at which the changes in the respiratory activity and the ethylene production in *Annona* species occur allows a close estimate of the expected shelf life for these fruits, as these events are associated to a series of other changes that result in the best quality for consumption. Bruinsma and Paull (1984) and Worrell *et al.* (1994) reported changes in the development of the flavor, the darkening of the peel and the softening of the soursop pulp during the autocatalytic ethylene production.

18.3 Maturity and quality components and indices

The beginning of the maturation is marked by several physiological events, whose importance and intensity vary according to the fruit. For soursop fruit, the rapid ripening is marked by an intense metabolic activity, which is responsible for abrupt changes, most of which are scientifically little known until now.

Due to the existing association of some of these physiological responses with quality components that define the consumer acceptance of the product, they can be used as maturity indexes, supporting the decision about the right time for harvesting or the best moment for consumption.

18.3.1 Dry matter

The percentage of dry matter in fresh soursop pulp is about 13.6 according to Leterme *et al.* (2006). This value is proximate to the one informed by Paull (1982) for the pre-climacteric phase. The author presented decreasing fruit dry matter values from the pre-climacterium on, so that on the occasion of the climacteric peak the percentage was 4.0.

18.3.2 Color and pigments

Although not all fruits change their color during ripening, it is one of the characteristics that are mostly associated with the harvest point and maturity for consumption (Tucker, 1993). The period, the velocity and the intensity of change vary according to the species and between cultivars of a same species (Kays, 1997).

The most representative changes occur on the level of chlorophyll degradation. Although the exact mechanism of this degradation has not been fully understood yet, it is presumed that the chlorophyll molecule is solubilized from the thylakoid membranes of the chloroplast to the stroma, where it is oxidized (Tucker, 1993).

Concomitant to the chlorophyll degradation there might be a synthesis of other pigments in some fruits (Tucker, 1993; Kays, 1997; Wills *et al.*, 2007). For soursop fruit, the changes in peel color are due to chlorophyll degradation. Worrell *et al.* (1994) report variations in the intensity of the peel color from the development on until the physiological maturity. On the occasion of the ripening of the fruits, Paull (1982), Aziz and Yusof (1994) and Lima *et al.* (2003b) observed that the peel color turned to a lighter green. On the other hand, Lima *et al.* (2003a) did not find significant variation in the chlorophyll level during the postharvest maturation of 'Crioula' soursop fruit. When senescence approaches, a browning can be noted that tends to be general (Paull, 1982).

Regarding the pulp color, the ripening of the soursop fruit does not imply in noteworthy changes, as it is determined only by brightness (Lima *et al.*, 2003a, b).

Considering that changes in the fruit color can coincide or not with the development of other characteristics associated with ripening, generally they must not be seen as secure means to evaluate maturation (Kays, 1997).

18.3.3 Soluble solids and sugars

The soluble solids content, defined as the percentage of solids dissolved in the juice extracted from the pulp, has been used as a maturity indicator for several

fruits and is constituted mostly by sugars. During maturation there is an increase in the soluble solids and sugar rates. This increase is attributed mainly to the hydrolysis of reserve carbohydrates which were accumulated during the growth of the fruit on the tree, resulting in the production of soluble sugars (Tucker, 1993; Kays, 1997; Wills *et al.*, 2007).

Soluble sugar content of many fruits is about 5 to 10% but can vary considerably according to the cultivar, the soil type and the climatic conditions during the period of plant life. Moreover, significant variation in the sugar content of climacteric fruits may occur during the period between the harvest and the ideal consumption point (Whiting, 1970). According to Borrero *et al.* (1995), the soluble solids content of soursop fruit increases during the different development stages until reaching 7.0 °Brix when the fruit is physiologically mature. The characteristic flavor, as well as the aroma, is achieved during storage (Borrero *et al.*, 1995), when the soluble sugar rate increases while there is a climacteric increase (Paull, 1982). However, Lima *et al.* (2003b) point out that a significant accumulation of soluble solids in soursop fruit happens on the occasion of the first respiratory peak.

Among the sugars that are present in the fruit pulp, the most important are glucose, fructose and sucrose. The disaccharide sucrose is the main non-reducing sugar, while glucose and fructose constitute the main reducing sugars. In soursop fruit, a characteristic increase in reducing sugar contents occurs during maturation (Lima *et al.*, 2003a). For non-reducing sugars, the available studies have presented differing responses. According to Chan Junior and Lee (1975), sucrose represents 62% of soluble sugars, while glucose and fructose total 22% and 17%, respectively. Aziz and Yusof (1994), however, obtained lower levels of sucrose than the ones of glucose and fructose, from the initial stages of fruit growth until ripening. During the postharvest maturation, as Lima *et al.* (2003a) have informed, the non-reducing sugar contents keep practically unaltered in 'Crioula' soursop fruit. It is likely that the enzymes acid invertase and sucrose synthase, mainly the former, hydrolyze the sucrose preventing it from accumulation (Ohyama *et al.*, 1995).

The proportion between the different types of sugar is an important quality attribute since they differ from each other in sweetness. Sucrose, for instance, has a higher sweetness level than glucose, whereas for both this level is lower than it is in fructose (Pangborn, 1963). Therefore, fruits with fructose contents higher than any other sugar contents are consequently sweeter.

18.3.4 Titratable acidity and pH

The changes in acidity are also important in the development of the characteristic flavor of fruit. Although several organic acids are found, generally only one or two accumulate in the same type of fruit (Kays, 1997).

For most fruits, the organic acid content diminishes with ripening due to the use of the Krebs cycle, during the respiratory process, and in the synthesis reaction of new compounds (Kays, 1997). Nonetheless, for soursop fruit (Paull, 1982;

Paull *et al.*, 1983; Bruinsma and Paull, 1984; Aziz and Yusof, 1994; Lima *et al.*, 2003a, 2003b) and for other annonaceae, like atemoya (Wills *et al.*, 1984) and cherimoya (Muñoz *et al.*, 1997), an increase in the contents of the referred acids has been verified during ripening.

In soursop fruit, titratable acidity increases slowly during the growth process (Borrero *et al.*, 1995) and the beginning of maturation (Aziz and Yusof, 1994). Along the maturation, however, the increase gets more accentuated (Paull *et al.*, 1983; Lima *et al.*, 2003a, 2003b). Of all the acids found, malic acid is the one that most accumulates while the fruit ripens. Paull *et al.* (1983) verified a seven-fold increase in the content of this acid, while the citric acid content just tripled. Therefore it is the increase of malic acid that contributes significantly to the acid flavor of the fruit, according to Paull (1982).

Studies carried out by Lima *et al.* (2003b) point out that the period of greatest increase in titratable acidity in 'Morada' soursop fruit coincides with the respiratory increase and the first CO_2 peak. This finding suggests that the increase might be a consequence of the glycolysis induced by the harvest, with intense glucose oxidation and starch hydrolysis, as has been suggested by Bruinsma and Paull (1984).

According to Livera and Guerra (1995), the increase in organic acids in soursop fruit may be associated with three possible causes: the catabolism of starch and cell wall carbohydrates, which also supply substrates for the synthesis of sugars and volatile compounds; the transformation of acid salts in free forms; and the low utilization of organic acids in respiration. It is likely that the latter is the main cause and that the others are of minor importance, since other fruit that do also have high starch content at the time of harvest present a decrease in titratable acidity after being harvested (Lima *et al.*, 2003a).

As a consequence of the changes in titratable acidity, the pH is concomitantly modified. During the development of the soursop fruit, the pH slowly decreases from 5.6 to 5.4. However, when the ripening process initiates, the pH drops abruptly to values around 3.6–3.7 (Aziz and Yusof, 1994; Lima *et al.*, 2003a).

18.3.5 Phenolic compounds

Studies on soursop indicate that there is a reduction in the phenolic contents during maturation (Paull, 1982; Aziz and Yusof, 1994; Oliveira *et al.*, 1994), but also that these quantitative alterations are little significant (Lima *et al.*, 2003a). Nevertheless, there might be considerable changes among some types of predominant phenolics.

The composition of phenolic compounds is determined by genetic and environmental factors, but can be modified by oxidative reactions during storage and processing. The two most important processes involve the antioxidant activity of phenols and the oxidative browning (Robards *et al.*, 1999). Some fruit are especially prone to browning, including soursop fruit (Oliveira *et al.*, 1994; Borrero *et al.*, 1995), and so their sensorial properties and nutritional value are affected (Mayer and Harel, 1979).

18.3.6 Firmness

Soursop fruit firmness is abruptly reduced in a few days after harvesting, as shown in Fig. 18.3 (Lima *et al.*, 2003b). According to the authors, the most important changes coincide with the first respiratory increase and the peak in ethylene liberation. On the other hand, Worrell *et al.* (1994) considered that the softening of soursop fruit started with the ethylene production and that, at the peak, all parts of the fruit would be soft already.

The loss of firmness of soursop fruit, similar to other fruits, must be accompanied by a decrease in starch contents, an increase in the solubility of pectin, and a loss of cell wall galactose (Aziz and Yusof, 1994; Lima *et al.*, 2003b).

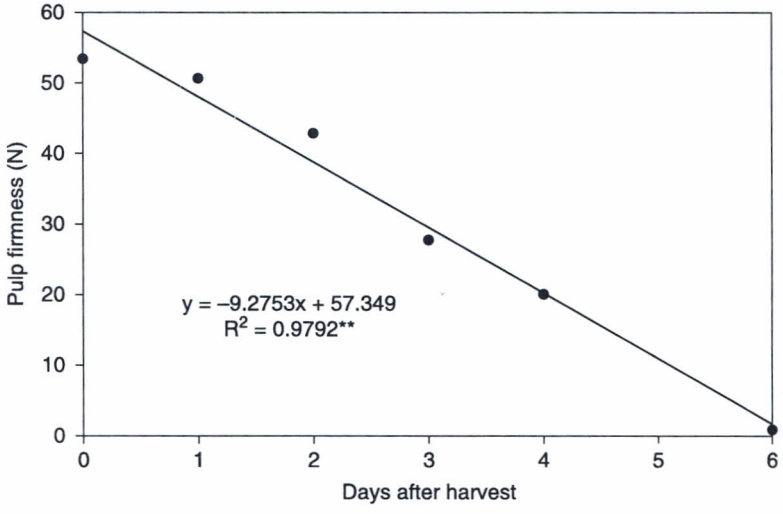

Fig. 18.3 Pulp firmness of 'Morada' soursop fruit harvested at physiological maturity and stored under room temperature. Source: Lima *et al.* (2003b).

18.3.7 Starch content

Soursop fruit is a typical example of a fruit with high starch content (Paull, 1982, 1990; Paull *et al.*, 1983; Castro *et al.*, 1984; Aziz and Yusof, 1994; Lima *et al.*, 2006; Nwokocha and Williams, 2009). Nevertheless, it is a highly perishable fruit (Paull, 1982; Mosca *et al.*, 1997; Lima *et al.*, 2003a, 2003b), which, when mature, keeps only approximately 15% of the starch content that had been accumulated until the physiological maturity (Lima *et al.*, 2006).

Along with ripening, starch is converted to soluble sugars (Paull, 1982, 1990; Paull *et al.*, 1983; Castro *et al.*, 1984) and organic acids (Paull, 1982; Castro *et al.*, 1984), reducing the firmness (Aziz and Yusof, 1994).

The characteristics of the starch granules of soursop fruit may respond for many of the textural attributes of the fruit. Nwokocha and Williams (2009) informed that

the shape of the granules is spherical, truncated and irregular. The granules have 60% starch content and the gelatinization temperature is 65.7–75.3°C.

18.3.8 Pectic substances

Aziz and Yusof (1994) and Lima *et al.* (2006) registered a decrease in the total pectin content as well as in the soluble fraction of sodium hydroxide during ripening of soursop fruit. This variance coincided with the reduction in pulp firmness.

The fractions that are soluble and water-insoluble (protopectin) have different levels of esterification and neutral sugar content. The non-soluble one, besides its high level of esterification, has neutral sugars both in the lateral chains and in the main one (Goldberg *et al.*, 1986), assuring the tissue firmness. This fraction produces soluble pectin after the hydrolysis (Esteban *et al.*, 1993).

Generally, these alterations in the pectin content are associated with enzymatic degradation. However, the structural conformation of the molecule that is united, at least partially, by non-covalent interactions reinforces the possibility of non-enzymatic degradation, influenced by an apoplastic pH, by the levels of inorganic ions in the cell wall, by non-enzymatic proteins, by the porosity of the cell wall and by structural barriers (Huber *et al.*, 2001).

According to McCollum *et al.* (1989), the apparently more important changes in the content of pectic substances are qualitative. They involve, for instance, differences in the proportions of cell wall sugars, like rhamnose, xylose, uronides and uronic acids, between the stages of development and maturation (Martin-Cabrejas *et al.*, 1994; Huysamer *et al.*, 1997).

Therefore, it has to be pointed out that the modifications in the cell wall polysaccharides of ripening fruit may derive from both the degradation and synthesis of polymers. Besides that, other mechanisms may be involved, as for instance: alterations in the cell wall pH, affecting the enzymatic activity; distribution of organic acids and inorganic ions; removal of lateral galacturonan chains; the calcium metabolism, as this ion normally binds to polygalacturonic acids, forming a structure known as *egg box* (Seymour and Gross, 1996).

18.3.9 Hydrolytic and oxidative enzymes activities

The ripening involves an intense metabolic activity in a period that, as has been pointed out above, can be quite short for some fruit, like soursop fruit. During this phase, quantitative and qualitative transformations can be verified in the normal set of enzymes that respond for a large part to the changes in flavor, pigmentation and softening (Kays, 1997). Others have their importance associated with the appearance of the fruit. This applies for some oxidases involved in tissue browning (Mayer and Harel, 1979, 1981, 1991).

During ripening, degradative changes in the cell walls are associated with the synthesis and/or activation of enzymes (Kays, 1997). Mainly, they are hydrolases whose action occurs at the same time that other biochemical and physiological activities are triggered (John and Dey, 1986; Wakabayashi, 2000).

The content of hydrolytic enzymes increases as a consequence of the changes in the synthesis and/or degradation rates and not as a result of the activation of a precursor molecule which was synthesized during the early stages of the development. It is considered that in the course of time an unstable product of gene expression (protein) becomes stable. For enzymes, which normally act in the cell wall or in the vacuole, this stability would be a consequence of a transport or transformation mechanism of primary products of gene translation (Brady, 1987).

It is improbable that one single enzyme is responsible for the changes in firmness. It is more likely that a complex interaction of enzymes is involved, including the ones that degrade starch (Tucker, 1993).

Pectin methylesterase and polygalacturonase

Aziz and Yusof (1994) only reported that there is activity of the PME enzyme in soursop fruit. However, Lima *et al.* (2006) quantified the activity, pointing out considerable increases over short periods of time, so that in the mature fruit the PME presented an activity that was twenty-three times larger than it was in the fruit at physiological maturity. Some studies have been carried out with the purpose to purify and characterize PME in soursop fruit, which is present in two isoforms (Arbaisah *et al.*, 1996, 1997a, 1997b).

Generally, it has been suggested that the function of the PME is to promote the desesterification of the galaturonanas in order to allow the action of the PGs (Giovane *et al.*, 1990; Kays, 1997). The PGs are pectolytic enzymes identified as endo-PGs (E.C. 3.2.1.15) and exo-PGs (E.C. 3.2.1.67). The endo-PG catalyzes the random hydrolytic break of the α-(1–4) bonds of the galacturonanas. The exo-PG, on the other hand, hydrolyzes the terminal galacturonosil residues of the non-reducing extremities of the molecule, liberating galacturonic acid (John and Dey, 1986; Seymour and Gross, 1996; Kays, 1997).

The activity of PG has been observed in several fruits (Abu-Sarra and Abu-Goukh, 1992; Ketsa and Daengkanit, 1999), where an increase during softening can be verified, possibly triggered by the ethylene production. The enzyme promotes the degradation of the middle lamella of the parenchyma cells, thus resulting in softening. Also, it may be involved in the autocatalytic liberation of uronic acids during the growth of certain fruits (Gallego and Zarra, 1998), in the degradation of solubilized pectic polymers during ripening (Redgwell *et al.*, 1992), and in the depolymerization of polyuronides (Yoshioka *et al.*, 1992).

In soursop fruit, Aziz and Yusof (1994) reported a sudden increase in the PG activity on the occasion of the climacterium. Lima *et al.* (2006) observed that, after the increase, the reduction in the activity of this enzyme coincides with a sudden drop in the pectin content and with a higher solubility of the pectins, indicating that the greatest part of the PG substrates was immediately used at the moment of maximum activity.

α- and β-galactosidases

Lima *et al.* (2006) observed that the activities of the α-GALs extracted from the cytosol and from the cell wall of soursop fruit occurred from the second day after

harvesting. The activity of the cytosol α-GAL in particular reached its highest value on the third day, followed by a 60% decrease. As to the activity of the α-GAL extracted from the cell wall, it was lower and decreased from the second day after harvesting, so that it represented continuously smaller proportions of the total α-GAL activity, suggesting that it might be of secondary importance in the softening of soursop fruit.

In its turn, β-GAL removes galactosil residues from the non-reducing ends of cell wall polymers. Its role in ripening is not yet quite clear, but some studies have emphasized its importance in softening (Burns, 1990; Ali *et al.*, 1995; Seymour and Gross, 1996; Gallego and Zarra; 1998). Ali *et al.* (1995) point it out as a key enzyme in pectin modification, and perhaps it complements the action of PG. Ranwala *et al.* (1992) associate it with the modification of pectic polymers and hemicellulosic components. On the other hand, in some fruit, the β-GAL is not likely to be involved in softening (Ketsa and Daengkanit, 1999).

In soursop fruit, the activity of β-GAL from cytosol is higher than the one of β-GAL from the cell wall, although it decreases during ripening, indicating that the enzyme may be exported to the cell wall (Lima *et al.*, 2006). The activity of the enzyme extracted from the cell wall increases during the first four days after harvesting and represents the highest proportion in the total β-GAL activity during the ripening of soursop fruit.

The mechanisms that are responsible for the liberation of galactosil residues are relevant not only due to the modification they promote in the cell wall, but also because of their role in the modulation of the galactose levels, which seemingly are important to the ripening process as a whole (Seymour and Gross, 1996).

Considering that soursop fruit undergoes progressive softening as it ripens, the enzymes that are likely to contribute more directly to the process are PME, PG and cell wall β-GAL. The importance of the latter two has to be pointed out, given that the intensity in which the softening occurs diminishes in the course of time. Therefore, it is expected that the activity of the involved enzymes be reduced as the process evolves. In a first moment, the PG acts in a more effective way. However, the precocious drop of activity suggests that β-GAL from the cell wall characterizes better this transformation (Lima *et al.*, 2006).

Amylase

Paull *et al.* (1983) determined the activity of amylase prior to the climacterium and in the mature soursop fruit, observing an increase of almost eighteen times from one stage to the other. Lima *et al.* (2006) emphasized the increase in amylase activity from the harvest until the fourth day, when starch contents equivalent to 25% of the initial were reached, the enzymatic activity stabilized. The response is coherent with the high starch breakdown rate in the fruit.

Polyphenol oxidase (PPO) and peroxidase (POD)

The activity of the PPO changes considerably during the development, ripening and storage of the fruit (Mayer and Harel, 1981). According to Silva (2000), the activity is highest during the development. Results obtained by Oliveira *et al.* (1994) confirm

this tendency for soursop fruit. Nevertheless, Lima *et al.* (2003a) observed an increase during the first four days after harvesting. These differences may be associated with the methods of extraction and quantification, as in the study by Oliveira *et al.* (1994) the specific activity of the enzyme was represented (based on the protein content), while Lima *et al.* (2003a) represented the total activity. Carbonaro and Mattera (2001) emphasized that the PPO activity is influenced by the cropping conditions. Moreover, the increase in activity of this enzyme, as well as the appearance of isoenzymes, is due to the *de novo* synthesis (Mayer and Harel, 1979).

The enzymatic browning of fruit may be avoided by inactivating the PPO, using ascorbic acid, SO_2 or heating (Badrie and Schass, 2009), or by reducing the quinones to phenols through reducing agents (Awad, 1993).

The PODs, in their turn, play a limited role in enzymatic browning as they depend on the availability of hydrogen peroxide (Robards *et al.*, 1999). However, the phenolic substrates can be oxidized in the presence of small quantities of hydrogen peroxide, and several compounds are susceptible to oxidation by these enzymes (Robinson, 1991).

The activity of POD in soursop fruit is still high right after harvesting, but turns severely reduced in the period from the second to the fourth day (Lima *et al.*, 2003a). Moreover, in contrast to many fruits, the activity of the POD is higher than the one of PPO, in these periods of great increments.

18.3.10 Aroma compounds

The production of volatile compounds in soursop fruit is parallel to the one of ethylene, reaching the highest level five days after harvesting, on the same occasion that the highest sugar and acid levels can be verified (Paull *et al.*, 1983), as well as the maximum sensorial preference. After the peak there is a drop in production of the main aroma compounds and volatiles appear to which the strange odor of the overripe fruit is imputed (Paull *et al.*, 1983). The same tendency is observed in relation to sugars and organic acids.

The prevailing compounds identified in soursop aroma after solid phase micro-extraction (SPME) were a-unsaturated methyl ester of the type R-CH5CH-COOCH3 (rethyl, butyl, hexyl) as methyl crotonate (rethyl), methyl 2-hexenoate (rbutyl), and methyl 2-octenoate (rhexyl) as well as aliphatic esters of butyric and caproic acids (Augusto *et al.*, 2000). Using gas chromatography/spectroscopic (GC/FID and GC/MS), esters of aliphatic acids were dominant odor compounds (approximately 51%), with 2-hexenoic acid ethyl ester (8.6%), 2-octenoic acid methyl ester (5.4%) and 2-butenoic acid methyl ester (2.4%) in essential oil extracted from soursop pulp (Jirovetz *et al.*, 1998). In addition, mono-and sesquiterpenes such as β-caryophyllene (12.7%), 1,8-cineole (9.9%), linalool (7.8%), α-terpineol (2.8%), linalyl propionate (2.8%), linalyl propionate (2.2%) and calarene (2.2%) are highly concentrated in the essential oil. The major volatiles identified by simultaneous distillation/solvent extraction and GC/MS analysis were methyl 3-phenyl-2-propenoate, hexadecanoic acid, methyl (E)-2-hexenoate, and methyl 2-hydroxy-4-methyl valerate (Pino *et al.*, 2001).

(Z)-3Hexen-1-ol was the main volatile present in mature green fruit, while Me (E)-2-hexenoate, Me (E)-2-butenoate, Me butanoate, and Me hexanoate were the four main volatiles present in ripe fruit.

The main compounds in the essential oil of the fresh soursop pulp were responsible for the esters of aliphatic acids dominated (~51%) with 2-hexenoic acid methyl ester (23.9%), 2-hexenoic acid ethyl ester (8.6%), 2-octenoic acid methyl ester (5.4%), and 2-butenoic acid methyl ester (2.4%) (Jirovetz *et al.*, 1998).

18.4 Preharvest factors affecting fruit quality

Fruit quality depends mostly on cultural practices. Besides, there is a great variation in fruit size and quality among plants, due to seed propagation. For this reason vegetative propagation is recommended, as it represents an efficient way to obtain highly productive plants and high quality fruits (Filgueiras *et al.*, 2002). According to the authors, the main factors that affect the soursop fruit quality are: genetics; environmental conditions (climate, cropping conditions, insolation, irrigation and proper plant nutrition, agrochemicals); proper pollination; harvest methods; and condition and physiological age of the fruit at harvest.

In Brazil, for example, production problems have included low fruit set due to poor pollination and adverse climatic conditions and the attack of several devastating pests and diseases. The most important pests are the fruit borer, *Cerconota anonella* Sepp, the seed borer, *Bephratelloides maculicollis Bondar*, the stem borer, *Cratosomus* spp., the 'irapua' bee *Triogona spinips*, the leafminer, *Prinomerus anonicola* Bondar, and some species of Membracidae, Coccidae, Diaspididae, and Aphididae (Braga Sobrinho *et al.*, 1998). The main pest of the soursop fruit in the West Indies is the mealy bug (*Maconellicoccus hirsutus*). Soursop fruit is subject to attack by soursop fruit flies, and red spiders are a problem in dry climates (Badrie and Schauss, 2009).

The most serious diseases in soursop fruit are caused by fungi, which assume an important character in the phases of blooming, fructification and post-harvest. The ones which stand out are anthracnose, caused by *Colletotrichum gloeosporioides* Penz., brown rot (*Rhizopus stolonifer* Soc.) and bark rot, caused by *Lasiodiplodia theobromae* (Pat), which rapidly invades the flesh, becoming brown and corky, but can be associated to *Phomopsis* sp. and *Colletotrichum* sp. Black canker caused by *Phomopsis anonacearum* occurs in the wet season, purple spots occurring at or near the distal end. As the lesions enlarge, the surface becomes hard and cracked (Filgueiras *et al.*, 2002; Badrie and Schauss, 2009).

Both the pests and the diseases that attack soursop and their fruits damage the quality in different intensities. In some cases, the damage is restricted to the skin and does not affect the taste or pulp integrity. When the appearance is affected, there is a commercial depreciation regarding the fresh fruit market but the fruit can still be destined to the industry. On the other hand, more severe damage can

prevent the fruit commercialization, on any market, once they affect fruit appearance, composition, and even result in fermentation.

18.5 Postharvest handling factors affecting quality

As it is a very perishable fruit, soursop fruit requires care in handling, from harvest to consumption, and in transit which is decisive to its conservation. The importance of this care is only the greater because of the scarcity of information on storage techniques that provide fruit quality support over the longest possible period.

The quality of a fruit can be understood as absence of defects or degree of excellence, involving sensorial, nutritional, as well as food safety aspects (Shewfelt, 1999). In the case of soursop fruit, according to Borrero *et al.* (1995), good quality is achieved when harvest occurs at the correct maturity stage. If harvested immature, soursop fruit present an irregular maturation, which seriously compromises its quality. When harvested ripe, they do not resist prolonged storage and losses occur. Alterations in quality occur, for fruit in general, mainly as a result of physiological changes (Shewfelt, 1999).

Several other factors are involved in quality, such as pulp browning. The phenomenon may be of enzymatic nature or not, but in both cases it results from melanin formation. The main differential is the fact that the non-enzymatic browning requires external heat, while the enzymatic one may occur at room temperature (Silva, 2000).

The main postharvest problems were due to deficient field practices and lack of knowledge on the fruit quality parameters by fruit growers. Also, inappropriate handling during the commercialization process increases the loss (Badrie and Schauss, 2009).

To reduce these problems, appropriate storage and handling techniques are essential. The use of techniques which delay ripening might prolong the conservation period of soursop fruit, preserving the quality characteristics that are peculiar to the fruit.

18.5.1 Temperature management

The importance of maintaining ideal packaging conditions for the fruit guarantees maximum quality preservation. For fruit with a reduced shelf life, as soursop fruit, storage at appropriate temperatures widen the possibility of commercialization on new markets, even though it may not be possible to achieve the improvement that has been made in extending the conservation period of other fruits (Maciel *et al.*, 1994; Livera and Guerra, 1995; Mosca, 1996; Silva *et al.*, 2001; Lima *et al.*, 2003b, 2006). The desirable situation corresponds to cooling the fruit, in the shortest possible time, to a temperature that reduces its metabolic activity without causing chilling injury, and to the maintenance of the cold storage chain during all stages of commercialization. The interruption of cold storage, apart from accelerating fruit metabolism, allows the condensation of vapor around the fruit, turning its surface vulnerable to infection by microorganisms present in the storage environment. The

problem becomes more serious when soursop fruit is ripe, because it develops an opening around the stalk and the peel ruptures easily when touched or in contact with too rigid and coarse surfaces. Even temperature variations due to cooling system faults, or negligence in entering and exiting cargo to and from the cold chamber, reduce the desired storage period and the shelf life of soursop fruit.

18.5.2 Physical damage

Care in handling and transport reduces or even avoids the occurrence of injuries. In soursop fruit, physical damage due to fall, vibration, friction or compression results in a dark coloration of the peel. This alteration in color depreciates the fruit (Zayas, 1966) and may accelerate the maturation and facilitate the infection by microorganisms, depending on the intensity. Moreover, inappropriate handling increases weight loss, which may significantly affect textural quality during the postharvest period (Kays, 1997).

18.5.3 Water loss

After harvesting, alterations in fruit weight are mainly due to water loss. A weight loss of merely 5% may cause withering and shriveling in many perishable products (Wills *et al.*, 2007). Nevertheless, water losses that result in a weight loss percentage of 4.6 (Lima *et al.*, 2003b) or 5.1, as shown in Fig. 18.4, and up to 11.8 (Mosca *et al.*, 1997) did not result in shriveling or other visible signs of withering in soursop fruit. The spurs, however, became flaccid more rapidly and turned dark.

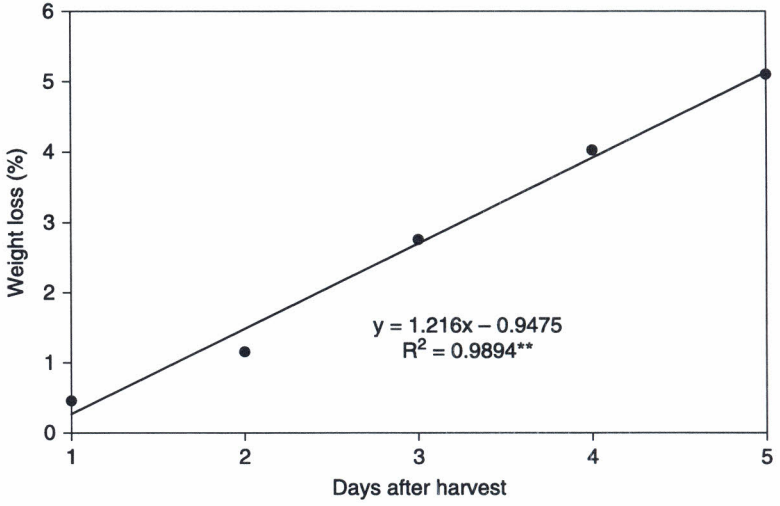

Fig. 18.4 Weight loss of 'Crioula' soursop fruit harvested at physiological maturity and stored under room temperature. Source: Adapted from Lima *et al.* (2003a).

18.5.4 Atmosphere

The lack of scientific information and the peculiarities of soursop fruit limit the availability of efficient techniques which might allow its quality preservation for a period of time that would be considered minimum for many other fruits. Therefore, there are no defined conditions to ensure the viability of storage under controlled atmosphere, for instance. Likewise, even though the quick and high response to ethylene might justify an intervention with substances that absorb or inhibit this gas, there is no commercial application. Some studies have experimentally tested the application of the ethylene inhibitor 1-methyl cyclopropane (1-MCP) in soursop fruit (Lima *et al.*, 2002a, 2004). Some more detailed information considers the use of coatings and modified atmosphere packaging (Guerra *et al.*, 1995; Silva *et al.*, 2001; Lima *et al.*, 2004).

18.6 Physiological disorders

Physiological disorders that affect soursop fruit during its growth, development and maturation phases have not been recognized. There are only records of the possibilities of chilling and heat injury occurrence from harvest on, under specific packaging conditions that might expose them to the causes of these disturbances.

18.6.1 Chilling injury

Although the inferior limit for the normal metabolism is the tissue's freezing point, some species show symptoms of chilling injury even in temperatures above that point (Luchsinger, 1999; Wills *et al.*, 2007).

The symptoms of chilling injury in soursop fruit are skin darkening, failure to ripen, pulp discoloration, poor flavor and aroma, maintenance or increase of pulp firmness, internal breakdown, loss of ripening capability, senescence acceleration, increase in rot, etc. (Maciel *et al.*, 1994; Salgado *et al.*, 1998; Badrie and Schauss, 2009). The occurrence of this damage depends on the species, the cultivar, the maturity stage and the cropping conditions (Luchsinger, 1999). In soursop fruit, chilling injuries at 12 °C were reported by Maciel *et al.* (1994), Mosca (1996) and Salgado *et al.* (1998). Filgueiras *et al.* (2002) have mentioned temperatures below 15 °C as resulting in the appearance of chilling injury symptoms, which are more evident in physiologically mature fruits.

18.6.2 Heat injury

Heat injuries are caused by the exposure to very high temperatures (above 27 °C), which can result in internal breakdown. The transformations that occur during fruit ripening can be modified by the excessive heat, with consequences to the appearance, sugar content, acidity and aroma. This kind of disorder is prevented by avoiding any unnecessary exposure of the fruits to heat, keeping them always

in the shade while they are in the orchard, lowering the field heat as quickly as possible and controlling the storage temperature (Filgueiras *et al.*, 2002).

18.7 Pathological disorders

As mentioned before, the main pathological disorders that attack soursop fruit are caused by fungi. They occur in the phases of blooming, fructification and postharvest. The most important are anthracnose, brown rot and bark rot, which rapidly invades the flesh, becoming brown and corky, but can be associated with *Phomopsis* sp. and *Colletotrichum* sp. Black canker occurs in the wet season as purple spots occurring at or near the distal end. These lesions enlarge and the surface becomes hard and cracked (Filgueiras *et al.*, 2002; Badrie and Schauss, 2009).

18.8 Postharvest handling practices

The limited knowledge of the fruit physiology and the restricted market have not yet allowed the adoption of more sophisticated postharvest procedures or techniques for soursop fruit. Thus there is a need for special care during harvest, when occasional damage may affect and reduce its shelf life.

18.8.1 Harvest operations

In the soursop orchard, the fruits do not ripen at the same time. Therefore, it is necessary to visit it frequently in order to identify fruits which have reached harvest point.

The harvest should be done manually with disinfected pruning scissors with curved, sharp blades and rounded, blunt tips, in order not to damage the fruit (see Plate XXXIV in the colour section). The cut should leave a peduncle of 1.0 cm approximately. Considering the large size of the fruit it is recommended that the soursop fruit be carefully held in one hand, while the scissors are used with the other.

Harvest should be done in the first hours of the day, avoiding the hot periods, which could heat the fruit and result in the browning of the spurs when touched. Once harvested, the fruit should be put in boxes covered with soft and flexible material with the stalk facing downwards and slightly inclined, and kept protected from the sun, rain and dust until taken to the packinghouse. It is also advisable to protect the fruits with paper or other soft material to avoid friction between fruits in the same harvest box. When more than one layer of fruits is used in the same box they should be separated by a sponge (Alves *et al.*, 2002).

The care already mentioned should be maintained during the transport to the packinghouse, preventing for instance excessively full boxes which may cause fruit damage while piling them into the vehicle.

18.8.2 Packinghouse practices

The postharvest operations for soursop fruit destined to the fresh fruit market include washing, drying, grading and sizing, packaging, pre-cooling and storage, as described next (Alves *et al.*, 2002).

- *Washing*: in the packinghouse, the fruits should be washed with chlorinated water (100–200 $mg.L^{-1}$ of free chlorine) so as to remove dirt, microorganisms and superficial residues. To achieve efficiency in this procedure, it is necessary to change the water periodically and pay special attention to temperature and pH, factors that determine the efficiency of the chlorine. After washing, the fruits must be dried before initiating the following stages.
- *Grading and sizing*: the selection is manual, eliminating immature, very ripe, or deformed fruits and as well those with stains or mechanical injuries. The fruits which are good for commercialization are classified according to the weight.
- *Packing*: in this stage occurs the most serious negligence with the quality of the soursop fruit, which in most of the cases is commercialized without any protection. Technically, it is recommended that individual fruits are wrapped in paper bags or polyethylene nets and arranged in cardboard boxes suitable for soursop fruit sizes.
- *Pre-cooling*: when cold storage is used, it is necessary that, prior to the storage in the cold chamber, fruits are rapidly cooled down, in specific tunnels, so that within a short period of time (4–6 hours) the pulp reaches the recommended storage temperature of 15 °C. The operation is carried out in tunnels that also keep the relative humidity in levels that are favorable to the fruit (85–95%, preferentially at 90%). When pre-cooling is accomplished, fruits will be kept in the cold chamber until the moment of distribution.
- *Refrigerated storage*: the cold chamber must keep the temperature and relative humidity at the ideal levels in which fruits were received after pre-cooling. From then on, cold chain must be maintained, as a requirement for the soursop fruits reaching their longest possible shelf life.

18.8.3 Control of ripening and senescence

Few studies have been carried out on the use of MA for soursop fruit. Guerra *et al.* (1995) and Maciel *et al.* (1994) have tested, respectively, the use of sugar ester and fatty acid pellicles and polyethylene films involving the packing boxes of soursop fruit stored at 16 °C. However, fruits did not ripen normally. Promising results were obtained by Silva *et al.* (2001), when using flexible polyethylene films in individual soursop fruit packing on polystyrene trays, stored at 12 °C and at 14 °C. Fruits stored at 12 °C under MA sustained a good quality for up to 22 days.

The fruit ripening may be delayed through the use of inhibitors of ethylene production and action (Abdi *et al.*, 1998). Among these, we can highlight the cyclopropenes: antagonist gases to ethylene, which compete with this hormone

for the binding sites in the membrane receptors. Among the three cyclepropene compounds (cyclepropene, 1-MCP and 3,3-dimethyl cyclopropene) that act as ethylene-action inhibitors, the second has concentrated most of the studies, due to its activity and stability (Sisler and Serek, 1997). Its application to soursop fruit is only experimental and requires further studies. Lima *et al.* (2002a, 2004) observed some delay in ripening due to the application of 1-MCP to soursop fruit stored at room temperature or under cooling, but the duration is short, when compared to what is observed for other fruits.

18.8.4 Recommended storage and shipping conditions

The ideal storage conditions correspond to those where the products can be stored for the longest possible time, without considerable loss of their quality attributes, like flavor, aroma, firmness, color and humidity content. Among the available conservation methods, cooling is the most used and efficient for the storage of fruits and vegetables (Chitarra and Chitarra, 2005).

Some studies carried out with soursop fruit reported that at temperatures of 22–23 °C, the fruits ripened in up to six days (Maciel *et al.*, 1994; Mosca, 1996; Lima *et al.*, 2003b). Raising the temperature to 26 °C, the shelf life was only five days (Lima *et al.*, 2006). On the other hand, on reducing the temperature to 21 °C, Livera and Guerra (1995) observed that the fruits reached consumption conditions in up to seven days. When the storage temperature was 15 °C, Mosca (1996) concluded that the time needed for ripening increased to nine days. In lower temperatures, like 12 °C and 14 °C, Silva *et al.* (2001) observed that the fruit was already improper for commercialization on the sixth day.

In general, storage time depends on the respiratory activity of the product, on susceptibility to humidity loss and on pathogen resistance (Wills *et al.*, 2007). The latter two depend on the environmental relative humidity. High humidity levels favor the development of microorganisms and low ones foster physiological disorders and uneven maturation, besides the loss of turgescence.

Associated with cooling, the application of wax based on polyethylene emulsion, containing also fumaric resins, preservative and water, reduces the soursop fruit mass loss and delays the increase in soluble solids content and firmness loss during soursop fruit cold storage at 15 °C and 86% RH (Lima *et al.*, 2004, 2010). The delay in firmness loss, specifically, occurs in the period of the greatest biochemical changes in soursop fruit, along with, for example, the increase in the activity of β-galactosidase and the first CO_2 peak.

The mentioned effects were obtained through the application of 200 $nL.L^{-1}$ of 1-MCP for 12 hours (Lima *et al.*, 2010). This ethylene inhibitor was responsible for the delay of the respiratory peak and the limited ethylene production in soursop fruit. When sprayed in association with wax, the effects of keeping the amylase activity stable and reducing the PG activity were added. In both cases, the commercial appearance of the fruits was preserved for eleven days, at 15 °C. However, the spraying of wax allowed a lower weight loss for 15 days of evaluation and an acceptable consumption appearance for 13 days.

18.9 Conclusions

The intense metabolic activity of soursop fruit during maturation results in a very short period of postharvest conservation. In general, the changes are abrupt and some of them are related to the climacteric peak. Recently, some of those changes, including enzymatic activity, have been studied, detailing responses that can contribute to define more efficient techniques, procedures and methods of postharvest conservation for soursop fruit. However, just a few researchers are dealing with this fruit and there are many unknown physiological and technological aspects. Even the correct identification of the physiological maturity is not easy or secure in some genetic materials.

The relatively distinct respiratory metabolism of soursop fruit require biochemical studies to find the key steps that stimulate the events related to organic acids accumulation, firmness loss and starch breakdown, for example. Pulp browning is another event that has importance when the fruit is destined to the industry. Likewise, techniques of molecular biology could be useful to increase the knowledge about soursop fruit metabolism. Then, there is a great opportunity to explore scientifically the soursop fruit behavior in remarkable phases, especially after the harvest on physiological maturity.

Careful handling during harvest and postharvest operations, besides an adequate adoption of cultural practices, including phytosanitary control are needed. The latter is a critical point in some producing regions where pest control is difficult. Then, efforts are necessary to propose an efficient integrated management of pests and diseases, contributing to the fruit quality. Regarding postharvest technologies, the improvement on adopted techniques and the recommendation of others depend on getting an established knowledge about the physiology and biochemistry of the fruit.

18.10 References

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