Sapota (*Manilkara achras* Forb.): Factors Influencing Fresh and Processed Fruit Quality

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**ABSTRACT**

Sapota (*Manilkara achras* Forb.) is an evergreen tropical tree, the fruit of which is used fresh and processed. Sapota, also known as sapodilla, contains high levels of ascorbic acid and phenolic compounds which contribute to its numerous purported human health benefits. The fruit is characterized by a climacteric ripening behavior with a short postharvest life at ambient temperature. The main limitation of postharvest shelf life is decay. Although low-temperature storage prolongs the postharvest life of sapota fruit, chilling injury can develop if the storage temperature is less than 14 °C. The storage life of sapota fruit can also be extended with the use of modified and controlled atmospheres and the use of other postharvest...
treatments such as 1-methyl cyclopropene and calcium application. Limited postharvest research has been conducted on sapota fruit over the last 30 years. This review discusses the preharvest and postharvest physiological and biochemical processes related to the maturation, ripening, and senescence of sapota fruit. In addition, the postharvest treatments, methods and technologies to maintain fruit quality and control of postharvest decay and physiological disorders are also reviewed. Future research is proposed, with an emphasis on proteomic and molecular approaches to investigate the mechanisms of sapota fruit ripening, senescence, and its susceptibility to chilling injury. The adoption of best postharvest handling practices and storage techniques developed from postharvest research and development will benefit the exploitation of sapota fruit onto world markets.

**KEYWORDS:** *Manilkara achras*; postharvest treatments; storage life; quality

### ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>ACC</td>
<td>1-Aminocyclopropane-1-carboxylic acid</td>
</tr>
<tr>
<td>AEAC</td>
<td>Ascorbic acid equivalent antioxidant capacity</td>
</tr>
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<td>CI</td>
<td>Chilling injury</td>
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<tr>
<td>H-ORAC</td>
<td>Hydrophilic oxygen radical absorbance capacity</td>
</tr>
<tr>
<td>LDPE</td>
<td>Low-density polyethylene film</td>
</tr>
<tr>
<td>MAP</td>
<td>Modified atmosphere packaging</td>
</tr>
<tr>
<td>1-MCP</td>
<td>1-Methyl cyclopropene</td>
</tr>
<tr>
<td>NMR</td>
<td>Nuclear magnetic resonance</td>
</tr>
<tr>
<td>PCA</td>
<td>Principal component analysis</td>
</tr>
<tr>
<td>PG</td>
<td>Polygalacturonase</td>
</tr>
<tr>
<td>PME</td>
<td>Pectin methylesterase</td>
</tr>
<tr>
<td>POD</td>
<td>Peroxidase</td>
</tr>
<tr>
<td>PPO</td>
<td>Polyphenol oxidase</td>
</tr>
<tr>
<td>SSC</td>
<td>Soluble solids content</td>
</tr>
<tr>
<td>TA</td>
<td>Titratable acidity</td>
</tr>
<tr>
<td>TAC</td>
<td>Total antioxidant capacity</td>
</tr>
<tr>
<td>TPC</td>
<td>Total phenolics content</td>
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### I. INTRODUCTION

A. Cultivars
B. Uses
   1. Fresh Fruit
   2. Cooking
   3. Medicinal Uses

### II. NUTRITIVE VALUE

A. Antioxidant Activity
B. Anticancer Activity
C. Potential Pharmaceutical Use
I. INTRODUCTION

Sapota is from the Sapotaceae family with a diverse and significant range of 700 species and 35 or 40 poorly defined genera (Peiris 2007). These shrubs and trees are widely distributed throughout the tropics (Parle and Preeti 2015), and are recognized by the expression of milky latex and alternate leathery leaves with parallel secondary and tertiary veins (Parle and Preeti 2015). There are many synonyms for the scientific name of sapota, including *Achras sapota* L.; *Achras zapota* L. var. *zapotilla* Jacq.; *Achras zapotilla* Nutt.; *Achras mammosa* L.; *Manilkara*...
Sapota is a medium to large tree with a rounded canopy and many horizontal or drooping branches (Peiris 2007). The mature sapota fruit is classified as an ellipsoid or ovoid berry (about 12–15 cm diameter) with a thin skin, covered with a brown layer (Lim 2013). The immature fruit is hard, gummy and very astringent, and becomes soft and sweet as the fruit develops and ripens. Flesh colors range from a light yellow color to dark-brown or sometimes reddish-brown. Flesh texture may be coarse and grainy or smooth which becomes soft, very juicy, and sweet with a pleasant flavor (Plate 4.2) (Lakshminarayana and Subramaniyam 1966; Camargo et al. 2016). Some fruit are seedless, but normally there may be from three to 12 seeds (frequently five), which are easily removed as they are loosely held in the center of the fruit. The seeds contain a range of phytochemicals such as sapotin, saponin, and sapotinine. The seeds should be removed before eating because they contain the toxin hydrocyanic acid (Peiris 2007; Cortez et al. 2013).

Plate 4.1. Sapota tree (See the color version of this plate in Color Plates Section.)
4. SAPOTA (MANILKARA ACHRAS FORB.)

Sapota is native to Central America, specifically in the adjacent areas of southern Mexico, along with northern Belize and north-eastern Guatemala. However, due to its high adaptability to different soil and climatic conditions, relatively low production costs, high nutritive value, export potential and generally high economic returns, sapota is now widely grown across the world (Agrawal and Dikshit 2008; Kunyamee et al. 2009). It is extensively grown in the tropics, particularly in Central and South America but it is now widely grown commercially in Mexico, India and across Southeast Asia including the Philippines, Vietnam, Malaysia, Indonesia, Thailand, Sri Lanka and Bangladesh (Lim 2013; Parle and Preeti 2015).

The largest producers of sapota in the world are India, Mexico, Guatemala, and Venezuela (Athmaselvi et al. 2014; Saxena 2014; Hiwale 2015). Sapota is an important fruit in India (Bhale et al. 2013), and is widely grown in the states of Gujarat, Karnataka, Maharashtra, Tamil Nadu, Andra Pradesh, and West Bengal. The state of Karnataka is the main producer of sapota in India, with 293,000 ha of plantations producing 360,000 MT of fruit each year (Suhasini et al. 2012).

**Plate 4.2.** External and internal images of round and elongated sapota fruit (See the color version of this plate in Color Plates Section.)
A. Cultivars

Many cultivars of sapota are available which differ in branching, foliage color, fruit shape, fruit texture, and color and pulp quality (Hiwale 2015). A small number of seeds with sweet pulp are the main characteristics of an acceptable fruit. Inferior cultivars contain hard flesh with a “sandy” texture. Over 35 cultivars are commonly grown in India, from which ‘Kalipatti,’ ‘Kirthabarthi,’ and ‘PKM-1’ are the most appreciated. ‘Kalipatti’ has oval-shaped fruit with few seeds (one to four) and a sweet flesh. ‘Kirthabarthi’ has small to medium-sized fruit with a rough fruit skin, while ‘PKM-1’ has thin skin, and a buttery and very sweet pulp. Moreover, crop improvement through clonal selection and planned hybridization has led to the introduction of many good new cultivars such as ‘DHS-1,’ which has round to slightly oblong fruit, with a very sweet, soft, granular and mellow flesh (Hiwale 2015).

B. Uses

1. Fresh Fruit. Sapota is widely grown and is considered as one of the best fruits in Central America. Ripe sapota fruit are generally eaten by cutting the fruit in half and the flesh is eaten with a spoon. The flesh is also added to salads or fruit cups, sherbets, milk shakes, and ice cream. A sweet sauce can also made from ripe fruit by pressing the flesh, adding orange juice, and covering with whipped cream (Peiris 2007).

2. Cooking. Sapota flesh can also be used as an ingredient in baking when combined with egg custard mix before baking. However, sapota is generally not cooked or preserved, but is sometimes fried (Peiris 2007). Cooking the fruit alters the flesh to a red color (Lim 2013).

3. Medicinal Uses. Sapota fruit has been used as a traditional indigenous medicine in many cultures (Lim 2013). The immature fruit have a high tannin content and when boiled they can be used to treat diarrhea. Infusions of the young fruit have also been reported to relieve lung complaints (Kulkarni et al. 2007; Peiris 2007).

Consumption of the fruit has been reported to decrease inflammation and pain in gastritis, boost immunity and prevent bacterial infection, which is thought to be due to the presence of ascorbic acid (Parle and Preeti 2015). It is thought to be good for the treatment of digestion and is used in the treatment of constipation. It is also useful for pregnancy where its high nutritional content can be used as a herbal
remedy (Parle and Preeti 2015). Moreover, sapota has been used for treating pulmonary diseases in an Indian context because of its anti-inflammatory, analgesic, and antimicrobial effects (Mund et al. 2016).

II. NUTRITIVE VALUE

Sapota is a highly nutritious fruit containing a wide range of beneficial components such as dietary fiber, fructose, glucose, sucrose, vitamins, minerals and diverse phytochemicals, fatty acids and polyamines. The nutritional content of sapota fruit and juice is presented in Tables 4.1 and 4.2. Fruit contain high concentrations of minerals such as potassium, calcium, iron, copper and zinc and phenolic components (Kulkarni et al. 2007; Mund et al. 2016; Sumathi and Shivashankar 2017). The decrease in astringency during fruit development and ripening has been shown to be the result of polymeric changes, the interaction of other components such as sugars, and to a reduction in the concentration of polyphenols as fruit size increases (Lakshminarayana and Subramanyam 1966; Lim 2013).

A. Antioxidant Activity

Sapota fruit are considered to be a high source of antioxidants as they contain over 3000 mg l\(^{-1}\) ascorbic acid equivalent antioxidant capacity (AEAC) per 100 g fresh sample (Shui et al. 2004; Lim 2013). Polyphenolics, with basic blocks of catechin or gallocatechin, or both, attribute significantly to the antioxidant activity of the fruit (Lim 2013). It has been shown that sapota juice has high antioxidant activity when assayed with 2,2-diphenyl-1-picrylhydrazyl (DPPH) as well as superoxide radical scavenging activity. The presence of carotenoids, phenolics and ascorbic acid has also been linked to the multiple radical-scavenging potential of sapota juice (Kulkarni et al. 2007; Lim 2013). Ma et al. (2003) isolated ten phenolic compounds from a methanol extract of sapota fruit, including methyl chlorogenate, dihydromyricetin, quercitrin, 4-0-galloylchlorogenic acid, myricitrin, (+)-catechin, (−)-epicatechin, (+)-gallocatechin, methyl 4-O-galloylchlorogenate, and gallic acid.

B. Anticancer Activity

Phenolic compounds from sapota fruit have been shown to possess a range of anticancer activities. For example, methyl 4-O-galloylchlorogenate isolated from sapota fruit has been shown to display cytotoxicity
in the HCT-116 and SW-480 human colon cancer cell lines, with IC\textsubscript{50} values of 190μM and 160μM, respectively (Ma \textit{et al.} 2003; Lim 2013).

Srivastava \textit{et al.} (2014) considered the effects of methanolic extracts of sapota fruit (MESF) on NALM6 (pre-B-cell leukemia) and K562 (chronic myelogenous leukemia) tumor cells of mice. This compound

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**Table 4.1.** Nutritional components of sapota (*Manilkara zapota*) fruit per 100g edible portion.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Approximate value</th>
</tr>
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<tbody>
<tr>
<td>Water</td>
<td>78.00 g</td>
</tr>
<tr>
<td>Protein</td>
<td>0.44 g</td>
</tr>
<tr>
<td>Total lipid (fat)</td>
<td>1.10 g</td>
</tr>
<tr>
<td>Ash</td>
<td>0.50 g</td>
</tr>
<tr>
<td>Total dietary fiber</td>
<td>5.3 g</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>19.96 g</td>
</tr>
<tr>
<td>Calcium</td>
<td>21 mg</td>
</tr>
<tr>
<td>Magnesium</td>
<td>12 mg</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>12 mg</td>
</tr>
<tr>
<td>Potassium</td>
<td>193 mg</td>
</tr>
<tr>
<td>Sodium</td>
<td>12 mg</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.10 mg</td>
</tr>
<tr>
<td>Copper</td>
<td>0.086 mg</td>
</tr>
<tr>
<td>Iron</td>
<td>0.80 mg</td>
</tr>
<tr>
<td>Selenium</td>
<td>0.6 μg</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>14.7 mg</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>0.020 mg</td>
</tr>
<tr>
<td>Niacin</td>
<td>0.200 mg</td>
</tr>
<tr>
<td>Pantothenic acid</td>
<td>0.2528 mg</td>
</tr>
<tr>
<td>Vitamin B-6</td>
<td>0.037 mg</td>
</tr>
<tr>
<td>Folate</td>
<td>14 μg</td>
</tr>
<tr>
<td>Vitamin A</td>
<td>60 IU</td>
</tr>
<tr>
<td>Palmitic acid</td>
<td>0.1 g</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>0.094 g</td>
</tr>
<tr>
<td>Oleic acid</td>
<td>0.521 g</td>
</tr>
<tr>
<td>Linoleic acid</td>
<td>0.011 g</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>0.005 g</td>
</tr>
<tr>
<td>Leucine</td>
<td>0.024 g</td>
</tr>
<tr>
<td>Lysine</td>
<td>0.039 g</td>
</tr>
<tr>
<td>Arginine</td>
<td>0.017 g</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>0.032 g</td>
</tr>
<tr>
<td>Lutamic acid</td>
<td>0.038 g</td>
</tr>
<tr>
<td>Proline</td>
<td>0.036 g</td>
</tr>
<tr>
<td>Lycopene</td>
<td>41.93 (μg 100g\textsuperscript{-1} DW)</td>
</tr>
<tr>
<td>Total phenolic</td>
<td>13.5(mg GAE 100g\textsuperscript{-1})</td>
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Table 4.2. Chemical composition of sapota fruit juice with pH 5.36 and titratable acidity 0.16% (% citric acid).

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Approximate value</th>
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<tbody>
<tr>
<td>Total soluble solids</td>
<td>20.68%</td>
</tr>
<tr>
<td>Reducing sugar</td>
<td>9.86%</td>
</tr>
<tr>
<td>Total sugar</td>
<td>11.06%</td>
</tr>
<tr>
<td>Protein</td>
<td>312.5 mg 100 g⁻¹</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>10.52 mg 100 g⁻¹</td>
</tr>
<tr>
<td>Carotenoids</td>
<td>0.92 mg 100 g⁻¹</td>
</tr>
<tr>
<td>Total phenolics</td>
<td>134.6 mg 100 g⁻¹</td>
</tr>
<tr>
<td>Ca</td>
<td>20.67 mg l⁻¹</td>
</tr>
<tr>
<td>K</td>
<td>6.15 mg l⁻¹</td>
</tr>
<tr>
<td>Fe</td>
<td>0.11 mg l⁻¹</td>
</tr>
<tr>
<td>Cu</td>
<td>0.09 mg l⁻¹</td>
</tr>
<tr>
<td>Zn</td>
<td>0.5 mg l⁻¹</td>
</tr>
</tbody>
</table>

Modified from Kulkarni *et al.* (2007)

was found to induce cytotoxicity by activating pro-apoptotic and down-regulating mitochondrial protective proteins. MESF induced depolarization and trans-membrane potential in mitochondria and the translocation of phosphatidyl serine from the inner to the outer leaflet of the cell membrane, and significantly upregulated pro-apoptotic proteins and apoptotic markers which hallmarked apoptosis initiation. MESF treatment led to cell death of approximately 80% at 2 mg ml⁻¹, and induced cytotoxicity in NALM6 and K562 cells with IC₅₀ values of 0.9 mg ml⁻¹ and 2.5 mg ml⁻¹, respectively, after 72 h of treatment. Moreover, they showed that tumor progression inhibition resulted in a threefold increase in lifespan in 50% of mice, thus suggesting its potential role in preventing the genesis and progression of cancer cells (Srivastava *et al.* 2014).

C. Potential Pharmaceutical Use

Sapota fruit pulp contains sapotin (a glucoside used in medicine to reduce fever), saponin, fixed oils, and other bitter alkaloids (Madhav and Khurana 2011). In formulating microemulsions of the antidepressant drug, escitalopram, a novel potent bioemulsifier extract from pulp was found to have potential. The biopolymer showed positive tests for the presence of proteins and carbohydrates. The polymer can serve potentially for formulating various drugs loaded into emulsions (Madhav and Khurana 2011; Lim 2013).
III. PHYSIOLOGICAL AND BIOCHEMICAL CHANGES DURING FRUIT MATURATION AND RIPENING

Mature sapota trees grown in semiarid rain-fed conditions produce two crops per year. The summer-harvested fruit are generally bigger in size and higher in yield compared to fruit harvested in the rainy season (Hiwale 2015). A single sigmoidal pattern of development characterizes growth of the fruit, where three unique stages of growth have been identified (Brito and Narain 2002; Yahia and Gutierrez-Orozco 2011). Cell division and maturation of the embryo occur during the first stage of growth following pollination, whilst the second stage occurs when growth is significantly decreased. The third and final stages of growth are characterized by cell enlargement which gives rise to full fruit size – the growth occurs within 5 to 7.5 months after fruit set (Lakshminarayana and Subramanyam 1966; Yahia and Gutierrez-Orozco 2011).

Identifying the best harvest indices of fruit is critical, as harvesting fruit after the optimum stage of maturity promotes rapid softening and more susceptibility to physical damage, whilst immature fruit are astringent and contain latex (Yahia 2004). There are significant maturity differences among fruit within a single tree, and even within a single cluster of fruit, although fruit maturity normally initiates at the base of the cluster and progresses to the tip. However, judging fruit maturity is difficult where cultivar differences play an important role in determining harvest time. Maturity for a specific sapota cultivar is often judged by appearance and size. Although some cultivars often shed the scruffy surface coat on their skin when mature (Love et al. 2014), rubbing the brown powdery “scruff” is not always a successful indicator of maturity index for all sapota fruit (Love et al. 2014). However, the shiny brown color and rounded stilar end of fruit are considered good maturity indices in some countries (Kute and Shete 1995; Yahia and Gutierrez-Orozco 2011). Waiting for the first ripe fruit to fall from the trees is commonly practiced commercially, but this is not an adequate method of determining maturity (Yahia and Gutierrez-Orozco 2011). Another good indicator of ripening is the lack of latex coming from the skin when it is scratched, as the latex content is reduced to almost zero when the fruit is fully mature (Yahia and Gutierrez-Orozco 2011; Love et al. 2014). The specific gravity of mature sapota fruit has been indicated to be between 1.025 and 1.10 depending on the cultivar; for example, for ‘Kalipatti’ it has been reported as being 1.10 (Awasarmal et al. 2011). Another maturity indicator is based on the days required from fruit set to maturity. Typically,
it is between 120 and 245 days from fruit set to maturity depending on the climate and cultivar, but the erratic flowering habit and the presence of fruit at all stages of development on the tree makes it difficult to determine the optimum harvesting time of the fruit based on this indicator (Yahia and Gutierrez‐Orozco 2011).

A. Respiration Rate and Ethylene Production

Sapota is a climacteric fruit which can be harvested when fully mature and then ripened off the tree (Yahia 2004; Morrison et al. 2011). It is generally shown that the fruit is characterized by moderate respiration rates at 5°C (10–20 mg CO₂ kg⁻¹ h⁻¹), and high levels of ethylene production, that is, higher than 100μl C₂H₄ kg⁻¹ h⁻¹ at 20°C (Mangaraj and Goswami 2006). Vishwasrao and Ananthanarayan (2016b) showed that fruit from the cultivar ‘Kalipatti’ had a respiration peak 3 days after harvest, and later decreased, typical of other climacteric fruits.

High levels of ethylene (e.g., 100μl l⁻¹ for 24 h at 20°C) have been shown to accelerate ripening (Kader 2009; Thompson 2014). Conversely, ripening can be delayed with the removal of ethylene from the storage atmosphere (Thompson 2014). Bhutia et al. (2011) showed the benefits of ethylene removal with ethylene-absorbant sachets during sapota fruit storage (see also Section VIII B).

Other postharvest treatments which have been shown to decrease respiration and ethylene production rates include hot air treatment and calcium chloride (CaCl₂) dips (Thompson 2014). Chittham et al. (2002) showed with ‘Ma-Kok’ fruit that treatment with hot air at 35°C for 12 h followed by dipping in 5% CaCl₂ for 30 min reduced the rates of respiration, ethylene production, and ACC oxidase activity.

B. Fruit Firmness

Fruit texture is one of the most important quality attributes for the eating quality of sapota. Fruit texture is commonly quantified as fruit firmness or fruit hardness, which have been used as an indicator of fruit maturity (Raharjo et al. 1998). Fruit softening and ripening of sapota is associated with a reduction in fruit firmness, where firmness can decline from 60N in early stages of ripening to 8N in ripe fruit (Qiuping et al. 2006). Vishwasrao and Ananthanarayan (2016b) showed that flesh firmness decreased rapidly at the peak of the respiratory climacteric and then did not change significantly during further ambient storage.
C. Pigments

Fruit color is an important consumer quality attribute, and is due to different pigments such as chlorophyll and carotenoids in the skin and flesh. Chlorophyll is responsible for the green background level in the skin of sapota fruit, and its concentration has been shown to continuously decrease during fruit ripening, denoting both a decrease in chlorophyll biosynthesis and an increase in chlorophyll degradation (Qiuping et al. 2006). Conversely, the concentrations of carotenoids have been shown to increase during fruit maturation and ripening (Kulkarni et al. 2007).

D. Volatiles

Numerous studies have been conducted on the aroma of sapota fruit (Pino et al. 2003; Laohakunjit et al. 2007; Poonsawat et al. 2007; Uekane et al. 2017). These authors have used different extraction and identification methods, which have resulted in different results. Some of these differences may also be due, in part, to the cultivar studied and to the stage of fruit maturity at which the sample was taken for analysis.

The use of headspace solid-phase microextraction (SPME) with gas chromatography-mass spectrometry (GC/MS) led to 23 volatile components being identified in ‘Kai’ sapota fruit (Laohakunjit et al. 2007). The major volatiles were ethyl acetate (29% of the total volatiles), acetaldehyde (22%), benzyl alcohol (12%), and 2-butenyl benzene (7%). Pino et al. (2003) identified a total of 69 aroma volatiles using GC/MS, where the major components were methanethiol (32%), hexadecanoic acid (26%), 3-hydroxy-2-butanone (7%), ethyl acetate (6%), isoamyl alcohol (6%), and 2-methyl-1-propanol (4%). Poonsawat et al. (2007), using a solid-phase microextraction (SPME) technique, further showed that the aroma profile of fresh-cut sapota fruit changed during shelf life. Hexanal was a major volatile at the initial day of fresh-cut ‘Malay’ sapota during cold storage, but acetaldehyde and ethyl acetate became predominant by days 3 and 6, respectively (Poonsawat et al. 2007). Moreover, Uekane et al. (2017) identified 72 volatile compounds in the headspace of sapota fruit using headspace–solid-phase microextraction-gas chromatography-tandem mass spectrometry (SH-SPME-GC-MS). These authors showed the main volatile classes in sapota fruit to be esters (33%), alcohols (27%), terpenes (18%), and others (21%). The authors further identified ethyl butyrate, isoamyl acetate, limonene, ethyl hexanoate, 6-methyl-5-hepten-2-one, n-nonanal, ethyl octanoate, 2-ethylhexanol, linalool, ethyl decanoate, borneol, a-terpineol, n-dodecanal, 1-decanol, phenethyl acetate, 1-dodecanol and ethyl linoleate for the first time in sapota fruit (Uekane et al. 2017).
E. Ascorbic Acid

Sapota fruit is a good source of ascorbic acid (Bose and Mitra 1990; Camargo et al. 2016), although the concentration of ascorbic acid rapidly decreases during ambient storage. For example, Vishwasrao and Ananthanarayan (2016b) showed that after 3 days of storage the fruit retained just 5.5% of their original ascorbic acid content. This rapid degradation of ascorbic acid indicates a fast catabolism during storage, which is a prerequisite for increased respiratory and antioxidant requirements during ripening (Mehta et al. 1980; Vishwasrao and Ananthanarayan 2016b). Ascorbic acid has been shown to be degraded in these later stages of storage as a result of the activities of phenol oxidase and ascorbic acid oxidase enzymes, which may be utilized for the production of other organic acids (Kostman et al. 2001; Vishwasrao and Ananthanarayan 2016b).

F. Minerals

Sapota fruit contain relatively high concentrations of potassium and calcium (Kulkarni et al. 2007; Sumathi and Shivashankar 2017), with potassium being the most abundant mineral (7.2 mg g⁻¹ DW). However, the concentrations of minerals in the fruit change during fruit growth. For example, Rastegar (2015) showed that the concentration of iron decreased from about 4.5 μg g⁻¹ DW in the initial phases of fruit development to 1.0 μg g⁻¹ DW in the full ripe stage. The concentrations of manganese have been shown to decline from about 7.0 μg g⁻¹ DW in the initial phase of fruit development to a minimum of 0.5 μg g⁻¹ DW in the full ripe stage (Rastegar 2015). Hamza et al. (2013) showed that sapota fruit contained high concentrations of iron (14.2 μg g⁻¹ DW), manganese (1.5 μg g⁻¹ DW), copper (1.7 μg g⁻¹ DW), and zinc (1.0 μg g⁻¹ DW). It should be noted that there are considerable differences in the concentrations of minerals between different nutrition studies, but these may be the result of differences in the environment and other growing conditions.

G. Sugars

Carbohydrates are the main constituents of sapota fruit, where the content of free sugars is high whilst starch is almost absent in the fully ripened fruit (Yahia and Gutierrez-Orozco 2011; Sumathi and Shivashankar 2017). The concentrations of individual sugars change during ripening, where levels of sucrose show the highest increase
during ripening, followed by glucose and fructose (Yahia and Gutierrez-Orozco 2011; Sumathi and Shivashankar 2017). However, overripe fruit usually contain lower levels of sucrose than glucose and fructose (Yahia and Gutierrez-Orozco 2011). The levels of total sugars contained in mature green to the half-green fruit stage have been shown to increase from 11% to 15% because of the increase in nonreducing sugars, which increased from 2% to 6% (Brito and Narain 2002).

H. Organic Acids

The major individual organic acids in mature sapota fruit are malic (18.25 mg g⁻¹ FW), citric (8.30 mg g⁻¹ FW) and tartaric (2.69 mg g⁻¹ FW) (Sumathi and Shivashankar 2017). Other less significant organic acids such as fumaric, gluconic and oxalic acids have only been identified at specific stages of development and ripening (Das and De 2015).

The flavor of sapota fruit is a balance between sugars and organic acids. Levels of titratable acidity (TA) in fruit have been shown to decrease from around 0.48% to 1.36% in the initial periods of fruit development to lower levels (0.11–0.41%) when the fruit is completely ripe (Yahia and Gutierrez-Orozco 2011). This decrease in TA during ripening has been shown to be irrespective of cultivar (Yahia and Gutierrez-Orozco 2011). The low levels of acidity and high soluble solids content (SSC) (Brix 15.8%) lead to an elevated SSC/TA ratio, which is characteristic of ripe sapota fruit (Brito and Narain 2002).

I. Proteins and Enzymes

The protein content of sapota fruit is generally low, with the protein level being shown to vary between 0.52% and 0.76% FW at the eating-ripe stage (Yahia and Gutierrez-Orozco 2011). The concentrations of proteins and soluble amino acids generally decline during ripening, but this is accompanied by an increased activity of several enzymes such as inulase, invertase, amylase, and phosphatase (Selvaraj and Pal 1984; Yahia and Gutierrez-Orozco 2011; Vishwasrao and Ananthanarayan 2016b). The concentration of soluble proteins has been shown to increase during storage. Camargo (2016) showed that fruit at harvest had an initial protein content of 1700 mg kg⁻¹, and this reached a peak of 2506 mg kg⁻¹ on the fourth day of storage at 27°C. However, in senescent fruit the protein concentration was 2129 mg kg⁻¹ (Camargo et al. 2016). These different levels are thought to be due to changes in metabolic pathways of maturation that involve the synthesis or activation of
hydrolytic enzymes, such as α-amylase, β-amylase and starch phosphorylase, that lead to an accumulation of inverted sugars and polygalacturonase involved in softening of the tissue and accelerating changes during ripening (Vishwasrao and Ananthanarayan 2016b).

The activities of other specific ripening-related enzymes such as catalase, pectin methylesterase (PME), peroxidase and adenosine triphosphatase have been shown to increase during the ripening of sapota fruit (Rao and Chundawat 1988; Yahia and Gutierrez-Orozco 2011). Polygalacturonase (PG) and PME are softening-related enzymes which have been shown to increase during ripening (Bautista-Reyes et al. 2005). Even at 1 day after harvest the PG activity in the flesh of mature ‘Makok-Yai’ and ‘Kra-Suay’ fruit has been shown to increase (Kunyamee et al. 2010). Ethylene was also shown to hasten the increase in PG activity in both ‘Makok-Yai’ and ‘Kra-Suay’ cultivars during ripening (Kunyamee et al. 2010). Moreover, Bautista-Reyes et al. (2005) reported that PME activity in sapota fruit during ripening increased, and reached its maximum levels when the fruit was fully ripe. Levels of β-galacturonase activity are not detectable in fruit at harvest, but have been shown to increase as the fruit starts to ripen (Morais et al. 2008).

Polyphenol oxidase (PPO) and peroxidases (POD) are involved in enzymatic browning (Tomás-Barberán and Espin 2001; Vishwasrao and Ananthanarayan 2016b) in fruit and vegetables, and their activities have been shown to increase during ripening and then to gradually decrease with senescence (Malhotra et al. 2009). Moreover, further studies have shown that sapota fruit possess maximum activities of PPO and POD coinciding with the respiratory climacteric, and then to subsequently decrease (Vishwasrao and Ananthanarayan 2016b).

J. Phenolic Compounds and Antioxidants

Phenolics are an important class of phytochemicals contributing to a range of physiological functions, including antioxidant activity. The concentrations of phenolic compounds generally decline during ripening (Lim 2013; Camargo et al. 2016). The total phenolic content, as measured using Folin–Ciocalteu reagent, has been shown to range from 2.7 mg of gallic acid equivalents g⁻¹ FW at the early stages of ripening down to 1.0 mg gallic acid equivalents g⁻¹ FW in the final stages of ripening (Rastegar 2015). Moreover, Vishwasrao and Ananthanarayan (2016b) reported that total phenolic levels decreased by up to 90% after one week of storage at ambient temperature. As some phenolic compounds are often astringent in taste, the reduction of phenolic content makes the sapota fruit more suitable for consumption (Wang et al. 2012;
The decrease in the concentration of total phenolic compounds during storage is related to different activities, including those of some degradative enzymes (Fawole et al. 2013). The major individual phenolic compounds in unripe sapota fruit include catechin, epicatechin, gallocatechin, 4-hydroxycatechins, chlorogenic acid, and gallic acid (Ma et al. 2003; Lim 2013). Proanthocyanidins have been identified in sapota fruit and have been suggested to be responsible for its high antioxidant activity (Shui et al. 2004; Lim 2013). Isabelle et al. (2010) showed that, among 38 different fruit, sapota fruit had the highest total phenolic content and hydrophilic oxygen radical absorbance capacity (H-ORAC). Sapota fruit have also been stated to contain leucoanthocyanidins, triterpenoids, and tannins which may relate to its antioxidant properties (Ma et al. 2003; Anand et al. 2004).

IV. PREHARVEST EFFECTS ON POSTHARVEST QUALITY

Relatively few studies have been conducted on the effects of preharvest treatments on the postharvest quality of sapota fruit. Bhalerao et al. (2010) examined the influence of different preharvest orchard calcium treatments on the quality and storage life of ‘Kalipatti’ fruit. They showed that the longest shelf life was observed following a preharvest spray of 1% calcium chloride, whilst the level of postharvest decay was lowest following a preharvest treatment of 0.5% calcium chloride. They further showed that weight loss was lowest and firmness was highest with a preharvest treatment of 1% calcium chloride. These results demonstrated the positive effects of calcium chloride for shelf-life extension and quality maintenance of sapota fruit.

The postharvest quality of sapota fruit grown under organic and conventional agricultural systems in northeast Brazil was evaluated by Oliveira et al. (2010). No significant differences were determined in fruit soluble solids concentration (SSC) between the management systems, but organically grown fruit had higher titratable acidity and vitamin C concentration compared to fruit from the conventional system. However, these comparisons were very limited in scope.

A preharvest treatment of gibberellic acid (GA$_3$) (200 μl l$^{-1}$) has been shown to prolong the shelf life of sapota fruit by decreasing weight loss and decay (Choudhury et al. 2003). Moreover, Chavan et al. (2009) showed that 150 μl l$^{-1}$ GA$_3$ increased the total sugar content of the fruit at harvest.
V. PHYSIOLOGICAL DISORDERS

A. Chilling Injury

Chilling injury (CI) is characterized by well-defined symptoms that are a consequence of exposure to low temperature. Sapota fruit is susceptible to CI (Moo-Huchin et al. 2013), and this is a major storage problem. Symptoms of CI in sapota fruit include dark-brown spots and pitting of the skin, localized dark spots, uneven hardness, failure to ripen, increased decay after transfer to higher temperatures, and poor taste and flavor (Mohamed et al. 1996; Yahia and Gutierrez-Orozco 2011). The development of CI symptoms can occur when fruit is stored at less than 5 °C within 10 days, but can also occur within about 3 weeks when stored at 6–10 °C (Kader 2009).

Postharvest treatments such as the use of controlled atmosphere (CA) storage, waxing, film packaging, or applications with polyamines, methyl jasmonate, methyl salicylate, or other natural compounds have been shown to alleviate CI in tropical fruits (Wang 2004). However, little research on these options has been conducted on sapota. Yahia (2004) reported that different edible coatings applied after harvest, such as ‘Semperfresh™’ and ‘Sta-fresh™’, maintained fruit quality for 40 days at 10 °C without showing CI symptoms. In addition, postharvest hot air treatment (35 °C for 12 h) followed by dipping in 5% CaCl₂ for 30 min, has been shown to lower CI symptoms in ‘Ma-Kok’ fruit (Chittham et al. 2002). CI symptoms have also been shown to be prevented following treatment with 1-methylcyclopropene (1-MCP) (Moo-Huchin et al. 2013).

B. Flesh Browning

Flesh browning is a major quality constraint affecting the cut surfaces of sapota fruit used in minimal processing. The browning is mainly triggered by the action of PPO, which catalyzes the oxidation of polyphenols in the vacuoles producing oxidized products responsible for the brown pigments and associated sensory and nutritional changes (Rosenthal et al. 2002). Ascorbic acid has been shown to be the most effective postharvest treatment to control the action of PPO in sapota fruit, and browning can be managed by using this treatment during processing (Cortez et al. 2013). The latter authors further showed that sodium azide, acetic acid, sodium metabisulfite and honey also inhibited PPO activity, but tartaric, citric and oxalic acids did not show any inhibitory action against PPO in sapota.
Edible coatings utilizing methyl cellulose and palm oil have been shown to decrease the browning of sapota fruit during storage at ambient temperature. Skin darkening was delayed by slowing the browning process caused by PPO and POD (Vishwasrao and Ananthananrayan 2016b).

VI. POSTHARVEST DISEASES

Postharvest diseases are one of the main causes of postharvest losses in sapota fruit which, being soft textured, are highly sensitive to exogenous microorganisms, especially fungi. The main postharvest diseases of sapota fruit are black mold rot (*Aspergillus niger*), sour rot (*Geotrichum candidum*), blue mold rot (*Penicillium italicum*), and anthracnose (*Colletotrichum gloeosporioides*) (Kader 2009). Other disease organisms include *Phytophthora palmivora* and species of *Pestalotiopsis* and *Phomopsis* (Snowdon 2010).

Among these postharvest diseases affecting sapota fruit, black mold rot causes significant losses during storage (Wagh and Bhale 2012b). Fruit infected with anthracnose at the mature fruit stage leads to considerable losses during storage, transit, and marketing. When the anthracnose fungus invades mature fruit the resultant lesion is small and relatively cosmetic, with a shallow area of hardened tissue (Mossler and Crane 2002; Ahuja and Chattopadhyay 2015). Soft rot caused by the fungus *Pestalotiopsis mangiferae* is another major disease of sapota fruit in many parts of the world. The disease appears as water-soaked spots covering the entire fruit within 3–4 days (Srivastava 2014). The rotted fruit then become soft and dark brown, with numerous acervuli being visible in the rotted zones. Fruit rots caused by *Phytophthora palmivora* also exhibit water-soaked lesions which become brown within 2–3 days. Subsequently, the whole fruit is covered with tufts of mycelium (Srivastava 2014).

Postharvest diseases significantly affect fruit physiology, morphology and biochemistry, and cause significant quantitative and qualitative losses (Bhale *et al.* 2013). For example, postharvest fungal diseases interact with the physiology of the sapota fruit to enhance senescence and infection (Gadgilé *et al.* 2010). Wagh and Bhale (2012a) showed that the levels of endogenous phenolic compounds in the flesh of sapota fruit decreased after infection with *Aspergillus niger*.

A. Control of Postharvest Diseases

The control of postharvest diseases in sapota fruit is essential for quality retention and successful marketing. *Geotrichum candidum*, causing sour rot, can be controlled with postharvest dipping in carbendazim
ranging from 2100μg ml\(^{-1}\) to 4000μg ml\(^{-1}\), and in mancozeb ranging from 80μg ml\(^{-1}\) to 300μg ml\(^{-1}\) (Wagh and Bhale 2012b). Active ingredients used for the control of selected diseases include azoxystrobin, mefenoxam, myclobutanil, hydrogen dioxide, carbonic acid, and phosphite, and *Bacillus subtilis* (Mossler and Crane 2002; Crane and Mossler 2003).

A preharvest spray with 50μl l\(^{-1}\) GA\(_3\) has also been shown to reduce postharvest *Fusarium* sp. infection in ‘PKM 1’ sapota, where no infection was observed for up to 6 days of storage (Sudha *et al.* 2007). Moreover, a preharvest spray with 50μl l\(^{-1}\) GA\(_3\), in combination with a postharvest treatment of GA\(_3\) and carbendazim, reduced the development of postharvest spoilage for up to 12 days (Sudha *et al.* 2007). Tsomu and Patel (2014) reported that a postharvest spray with calcium chloride (5000mg l\(^{-1}\)) for 5 min could decrease postharvest spoilage of ‘Kalipatti’ sapota fruit for up to 12 days at ambient temperatures. They suggested that this may be due to the presence of higher calcium in the peel and the pulp, resulting in a stronger intracellular organization and rigidified cell walls (Tsomu and Patel 2014).

Research with biological control agents such as *Trichoderma* sp., including *T. koningii* and *T. pseudokoningii*, has shown the potential of these biological control agents to inhibit and control postharvest diseases in sapota fruit (Bhale *et al.* 2013). Further research in this area should focus on *in vivo* studies on the efficiency of the *Trichoderma* species as biocontrol agents, where the fruit is dipped into a suspension of *Trichoderma* after harvest (Bhale *et al.* 2013).

VII. POSTHARVEST TECHNOLOGY

The shelf life of sapota fruit is very short (2–3 days) at ambient temperature, and postharvest losses can commonly reach up to 30% (Polara 2013). Thus, there is a need to improve postharvest systems to preserve quality and prolong the postharvest life of the fruit.

Sapota fruit are harvested from the tree by cutting the peduncle, using a knife or secateurs, where fruit selection is usually based on size and maturity stage (Polania Trujillo 1986; Yahia 2004). Fruit are usually carried to local market in bamboo baskets, using banana leaves as a lining material to protect the fruit from abrasion and excessive damage. A foldable transportation container of 10kg capacity has been designed to minimize transportation losses of sapota fruit (Gontia 2016). This has enclosed conditions for protecting the produce from adverse climate and microorganisms. Maximum firmness, marketable fruit and sensory score, and minimum weight loss of sapota fruit have been observed.
when using this container (Gontia 2016). In addition, bruising and impact damage and decay were substantially decreased with the use of the foldable plastic container as compared to a gunny bag, perforated polypropylene bag, corrugated fiber board (CFB) carton, egg tray in CFB carton, or plastic crate (Gontia 2016).

Mature fruit are picked with or without the stalk (peduncle). Immediately after harvest a white latex exudes from the stalk, and should be removed because if it remains inside the fruit it coagulates and downgrades quality. The process of removing the latex is called “bleeding,” where the freshly harvested fruit are placed into a container with water. Bleeding is stimulated by scraping the stalk end with the thumbnail or with a sharp object. In addition, the fruit are scrubbed with a piece of cloth to remove the bloom, and then allowed to dry by placing them with their stalk ends down. A continuous mechanical system has been developed to clean sapota fruit in India. This is optimized to process up to 550 kg of fruit per hour with 100% cleaning efficiency and without causing damage to the fruit (Gontia 2016).

Pre-cooling is one of the primary postharvest operations required to maintain quality and to prolong postharvest life. The pre-cooling of ‘Kalipatti’ fruit at 8°C for 8 h has been shown effective in prolonging the postharvest life by lowering the percentage of spoilage, lowering losses from physiological disorders, and maintaining fruit firmness. Pre-cooling has also been shown to reduce the increase in soluble solids concentration (SSC) and to increase the organoleptic rating with regards to color, taste, and overall acceptability (Polara 2013).

**A. Grading and Packing**

Grading classifies fruit into uniform sizes and grades for the market, and is a vital prerequisite step in marketing sapota fruit. Grading can be conducted either manually (Varshney et al. 2005) or mechanically (Ukey and Unde 2010), where size and maturity can be used as grading indicators. Efficient grading operation, on the basis of physical dimensions of sapota fruit, can be made with the help of a mechanical sapota grader. The result is a product that is consistent in volume and shape and packs easily (Ali and Mandhar 2012). Fruit which have decay or mechanical injury are discarded (Yahia and Gutierrez-Orozco 2011).

Most countries use standardized grading systems for sapota fruit where in all cases the fruit must be fresh in appearance and free from any foreign matter, pests, and diseases. Fruit must be mature, of similar varietal characteristics, clean, well-formed, of similar color, and free from fruit fly, decay, anthracnose, mechanical and chilling injury. Sapota are
normally classified, based on the quality of the fruit, as Extra Class, Class I, and Class II (Philippine National Standard 2011; Thai Agricultural Standard 2011). In the Extra Class, the fruit must be of superior and uniform quality. Fruit in Class I must be of good quality, free from slight defects in shape, color, and skin defects (i.e., bruises) which should not exceed 5% of the surface area. In Class II, fruit do not meet the quality requirements for inclusion in the higher classes but satisfy the minimum requirements specified in this class, namely defects in shape, color, and skin defects (i.e., bruises) not to exceed 10% of the surface area. Fruit can also be graded into six categories depending on their size, viz., jumbo (more than 221 g), extra class (181–220 g), large (141–180 g), medium (101–140 g), small (60–100 g), and very small (<60 g) (Philippine National Standard 2011; Thai Agricultural Standard 2011). In addition, fruit in each package should be uniform and contain only sapota of the same origin, variety and/or commercial type, quality and size, and appreciably of the same degree of ripeness and development (Philippine National Standard 2011; Thai Agricultural Standard 2011). Standards for export of ‘Kalipatti’ sapota developed in India are: size – >5.0 mm diameter (70 g weight); color/texture – corky brown, smooth surface without any latex deposit on skin; taste – sweet; packaging – corrugated cardboard boxes with 16 fruits (4 × 4) including an ethylene-absorbant material.

Each market has different specifications and uses different packing materials but, regardless, sapota fruit must be packed properly in a suitable container. The materials used inside the package must be new, clean, and of good quality to avoid any external or internal damage to the produce. In many markets such as India, after grading, fruit are packed in single-layer trays with rice straw as padding material between fruit in fiberboard or wood flats (25–49 counts and 4.5 kg capacity). To avoid injury, the fruit weight should not exceed 20 kg per box (Yahia and Gutierrez-Orozco 2011; Love et al. 2014). Kenghel et al. (2015) compared a range of different filling materials and showed that coconut coir performed best and was the most economical filling material for the storage of ‘Kalipatti’ sapota fruit. However, all containers must meet the quality, hygiene, ventilation and strength characteristics to ensure optimum handling, shipping and preservation of the fruit (Philippine National Standard 2011; Thai Agricultural Standard 2011).

B. Storage

Like many other tropical fruits, sapota fruit have a short storage and shelf life. The optimum storage conditions are 14°C and 90–95% RH (Kader 2009), where fruit can be kept for 14–28 days (Yahia 2004).
CI can be induced under storage at lower temperatures, whilst storage at higher temperatures hastens quality deterioration. Yahia (1998) reported that the storage life of sapota fruit was increased from 13 to 18 days at room temperature when stored in an atmosphere of 5 kPa CO₂, 21 days in 10 kPa CO₂, and up to 29 days in 20 kPa CO₂. Freshly harvested ‘Cricket Ball’ fruit stored under 2 kPa O₂ combined with 10 kPa CO₂ has been shown to have an extended postharvest life about four- to fivefold that of control fruit under ambient conditions, by minimizing changes in physico-chemical characteristics and slowing down the process of ripening (Emerald et al. 2001). It has generally been shown that the storage life of sapota fruit can be improved beyond 2–4 weeks with optimal storage conditions, including the use of modified and controlled atmospheres. This is discussed in more detail below in the section on modified-atmosphere packaging (MAP).

Hypobaric storage involves the storage of produce under reduced-pressure conditions. Hawa (2005) showed that storage of sapota fruit at 10°C under a pressure level of 30 kPa reduced respiration rate and weight loss.

VIII. POSTHARVEST TREATMENTS

A. Ethylene Management and 1-Methylcyclopropene

1-Methylcyclopropene (1-MCP) is widely used to delay ripening and softening of climacteric fruits such as apple (Morais et al. 2008). Moo-Huchin et al. (2013) indicated that treating sapota fruit with 1-MCP (1 μl l⁻¹) followed by storage at 16°C prolonged the shelf life for up to 28 days. Furthermore, treatment with 1-MCP considerably decreased respiration rates. Moo-Huchin et al. (2013) showed that the treatment of fruit with 1-MCP resulted in firmer fruit, while Morais et al. (2008) showed that 1-MCP treatment of ‘Itapirema-31’ sapota fruit significantly delayed the rate of fruit softening, with less extensive solubilization of polyuronides, hemicellulose and of free neutral sugars when compared with control fruit. Moreover, Qiuping et al. (2006) showed that treatment with 1-MCP (at 40 or 80 nl l⁻¹ for 24 h at 20°C) markedly inhibited the rates of respiration and ethylene production, and ethylene-induced ripening processes such as softening and chlorophyll degradation were delayed. The same authors showed that 1-MCP treatment delayed the appearance of the PG activity peak by an additional 6 days, and 1-MCP-treated fruit had higher concentrations of SSC, TA, and ascorbic acid at the end of storage. These studies have shown that 1-MCP is a potent ethylene action inhibitor in sapota fruit, and the application of 1-MCP.
is a feasible technology for ripening inhibition and quality maintenance of harvested sapota fruit to allow extended storage and marketing.

B. Ethylene Management and Low-Ethylene Storage

Storage in low-ethylene atmospheres has been shown to increase the storage life of other climacteric tropical fruit such as banana (Wills et al. 2014). Bhutia et al. (2011) showed that the application of ethylene-absorbent materials (e.g., sachets containing KMnO₄) could be used to manage sapota fruit ripening. They showed the use of in-package ethylene absorbent to be dependent on the degree of ripening of sapota fruit, where the response was maximum in mature fruit, and delayed the ripening of fruit and prolonged marketable life for up to 13 days at ambient temperature (25–27°C). A major reduction in postharvest decay (from approximately 40% to around 12–15%) was also observed (Bhutia et al. 2011). Thus, the use of low-ethylene storage, such as when using ethylene absorbers in packed boxes of sapota fruit during long-distance transportation, could be a useful postharvest technology for delaying softening by removing the deleterious effects of ethylene around the fruit, delaying ripening, and further slowing down metabolic activities. This would have significant benefits where refrigeration is not available (Wills and Golding 2015).

C. Plant Growth Regulators

Plant growth regulators are an integral component of tree fruit production, and have also been studied as postharvest treatments to enhance fruit quality. Gibberellic acid (GA₃) is known for its general anti-senescing properties which have been shown to delay fruit ripening (Tsomu et al. 2015). Combined treatments of GA₃ (150 mg l⁻¹) dips and storage at 12°C have been shown to increase the storage life of ‘PKM-1’ and ‘Kalipatti’ sapota (Patel et al. 2010).

Studies on the effects of various concentrations of ethephon (2-chloroethylphosphonic acid) on ripening of fruit were carried out on ‘Kalipatti’ and ‘Cricket Ball’ cultivars. Fruit dipped twice in ethephon solution (1000 μl l⁻¹) resulted in superior ripening after 3 days, with pleasant flavor, high SSC, lower acidity, and acceptable sensory quality (Bons et al. 2016).

D. Calcium

Calcium plays a significant role in postharvest quality, due to its role in plant metabolism and membrane stability (Bahmani et al. 2015). Dipping sapota fruit in calcium chloride (CaCl₂) has been shown to be
effective in reducing weight loss, spoilage, maintaining fruit firmness, and increasing shelf life (by up to 12 days) of ‘Kalipatti’ fruit stored at room temperature (Tsomu and Patel 2014). Vacuum infiltration has been shown to improve the efficiency of calcium dips. Dhua et al. (2006) showed that sapota fruit could be stored for 16 days at 8°C without deterioration in quality following vacuum infiltration with CaCl₂ for 5 min. Fruit infiltrated with higher concentrations of calcium remained firmer and had higher SSC and sugars compared with those infiltrated with lower concentrations of calcium, and also untreated fruit. Moreover, gummy spot formation on the fruit surface due to milky latex was alleviated by dipping sapota fruit immediately after harvest in 1% calcium hydroxide for 5 min followed by wet rubbing, which improved the appearance of the fruit and extended its postharvest life (Tandel and Patel 2011).

E. Essential Oils

Essential oils are a wide range of secondary metabolites, which have a broad spectrum of antimicrobial, antioxidant, and regulatory roles (Bahmani et al. 2015). The application of thyme (Thymus vulgaris) essential oils in combination with CaCl₂ dips was evaluated on the quality of ‘Oval’ sapota fruit (Bahmani et al. 2015). Thyme essential oil alone or in combination with CaCl₂ completely inhibited the growth of fungi on fruit during storage. The use of thyme essential oil at low concentration (250 μl l⁻¹) with CaCl₂ also had a positive effect on maintaining fruit firmness, reducing weight loss, and enhancing fruit appearance. CaCl₂ at 2% and a high concentration of essential oil (500 μl l⁻¹) maintained the highest fruit firmness, but the use of essential oil at this concentration also caused skin and flesh discoloration and an unpleasant odor and taste (Bahmani et al. 2015). It is suggested that thyme essential oil with or without low concentrations of CaCl₂ could replace the use of chemical fungicides for the control of decay-causing fungi on sapota fruit, and increase its postharvest life.

F. Edible Coatings

Edible coatings have been reported to play a major role in maintaining the quality of a wide range of fruits (Dey et al. 2014). These authors studied the effect of corn starch on the storage life and quality of sapota fruit, and showed that the coating delayed disease occurrence and physiological and biochemical losses (e.g., change in weight, ascorbic
acid content, phenolic content, and color). Chitosan coatings on sapota fruit have also been shown to maintain fruit quality, with lower weight losses and respiration rates (Ahlawat et al. 2015). The same authors further showed that after 2 weeks’ storage the 1.5% chitosan-coated sapota had no deterioration in fruit quality. The use of other coatings, such as methyl cellulose and palm oil, have been shown to lower the activities of PPO, POD and PME, and delay the loss in phenolic compounds in fruit (Vishwasrao and Ananthanarayan 2016a). Moreover, pectin-based edible coatings have been shown to prolong the shelf life of sapota fruit for up to 11 days by delaying changes in physico-chemical factors such as weight loss, SSC, pH, total acidity, ascorbic acid, firmness and color (Menezes and Athmaselvi 2016).

Aloe vera is used extensively in the food and cosmetics industries, and has been shown to have beneficial effects on the quality of fresh fruits (Martínez-Romaro et al. 2006). Padmaja et al. (2015) showed that a dip treatment in an aloe vera coating was effective in maintaining fruit quality, with an extension of postharvest life by up to 20 days (Padmaja et al. 2015).

Palm oil coatings have also been tested and have shown benefits in fruit quality after storage, such as lower rates of weight loss, firmness, total soluble solids and increased shelf life for up to 15 days (Binti Arifin 2009). These results suggest that edible coatings could be novel and commercial means for maintaining sapota fruit quality.

G. Heat Treatments

Heat treatments have been widely used as postharvest quarantine treatments, and also maintain fruit quality during storage. For example, the postharvest life of ‘Co-1’ and ‘Co-2’ sapota fruit was extended for up to 14 days when fruit were dipped in hot water at 50°C for 5 min after harvest (Vijayalakshmi et al. 2004). The hot water treatment maintained quality parameters such as SSC, total sugars, and SSC/TA ratio. Chittham et al. (2002) also showed that sapota fruit quality was maintained for up to 40 days using fruit treatment with hot air (35°C for 12h), followed by dipping the fruit in 5% CaCl₂ for 30 min. As sapota fruit can host quarantine pests such as fruit flies, postharvest disinfection treatments are required to kill quarantine pests in the fruit to allow market access. The efficiency of the thermal treatment to kill the larvae of the quarantine pest Mediterranean fruit fly (Ceratitis capitata) was evaluated, and showed that vapor, hot water and hot air at 50°C for 75–90 min were all efficient in killing larvae (Lima et al. 2006).
H. Irradiation

Low-dose irradiation is used as a phytosanitary treatment to allow market access, and can be used to maintain fruit quality. Srinu (2014) showed that ‘Kalipatti’ fruit treated with 200 Gray (Gy) retained higher firmness and lower sugar content when compared with higher treatment doses and non-treated control fruit. Srinu et al. (2015) further showed that the irradiation of sapota fruit with 200 Gy irradiation, followed by storage at 15 °C, increased postharvest life to 26 days compared to 15 days for untreated fruit. However, fruit treated with doses higher than 400 Gy were softer and had a shorter shelf life, and developed injury and spoilage, compared to fruit irradiated at lower doses (200 Gy). Higher treatment doses (800 Gy) caused brownish spots on the surface of the fruit within 3 days of storage. Srinivas et al. (2012) also reported that 200 Gy treatment retained a higher firmness of ‘Kalipatti’ fruit and that higher treatment doses resulted in fruit damage.

I. Modified-Atmosphere Packaging

Modified-atmosphere packaging (MAP) involves modification of the atmosphere inside produce packaging to provide lower levels of oxygen (O₂) and higher levels of carbon dioxide (CO₂), which can delay fruit ripening, reduce respiration rate, and maintain fruit quality (Antala et al. 2014). MAP, using low-density polyethylene (LDPE) bags, has been shown to generate 5 kPa O₂ + 5 kPa CO₂ or 5 kPa O₂ + 10 kPa CO₂ inside modified atmosphere bags, which prolonged the postharvest life of ‘Kalipatti’ fruit for up to 49 days at 6 °C (Antala et al. 2014). Dash et al. (2012) proposed a model for sapota fruit packed in modified atmosphere using different packaging materials and based on the respiration rate and permeability of the packaging material. The most suitable packaging films for sapota fruit were determined to be LDPE, polyvinyl chloride, polypropylene and polystyrene films, whilst saran (a number of polymers made from vinylidene chloride, especially polyvinylidene chloride along with other monomers) and polyester films were found to be unsuitable (Dash et al. 2012). A comparison of the storage effects of LDPE bags with different gauges (100-, 200-, 300-gauge) and three different ventilations (0.8, 1.2, and 1.6%) was conducted on mature ‘Kalipatti’ fruit. Fruit stored in LDPE bags had better quality and longer shelf life, whilst fruit stored in 200-gauge LDPE bags with 1.2% ventilation had a maximum shelf life of 32 days and maintained the highest quality (Bindu Praveena et al. 2013). The longer shelf life and better quality of fruit in LDPE bags was due to the reduced permeability of the LDPE bags.
for O₂ and an accumulation of CO₂, coupled with low temperature. This resulted in lower respiration rates, a delayed onset of ripening, and slowing of the activity of cell-degrading enzymes (Bindu Praveena et al. 2013). A range of other wrapping materials such as newspaper, cling film and polyethylene of 0.05 and 0.1 mm thickness, and two wrapping methods (i.e., individual wrapping and lining), have been assessed, and showed individual wrapping of fruit in clingfilm to be the best method for reducing water loss and decay (Pahel et al. 2015). Fruit packed in 100-gauge polypropylene bags with 0.1% perforation resulted in a maximum total storability of 21 days (15 days at 15 °C and 6 days at room temperature) (Srinu et al. 2014). Other coating treatments such as bees wax have been shown to provide a good barrier to water loss and also to help maintain the texture of fruit under both refrigerated and ambient conditions (Morrison et al. 2011). For example, a bees wax coating was found to be superior in maintaining quality compared to cling wrap (Morrison et al. 2011). These results clearly demonstrate the potential of MAP to be an effective aid to prolong the shelf life of sapota fruit.

IX. NON-DESTRUCTIVE METHODS FOR IDENTIFYING FRUIT MATURITY AND QUALITY

Identifying the maturity stage of sapota at harvest is very difficult as no external color changes occur during fruit development and ripening processes (Aziz et al. 2001). As sapota flowers and fruit form in clusters of two to four, there is a range of maturities within each flowering/fruit cluster. This variability in fruit maturity causes significant problems for packers and consumers. A number of non-destructive methods can be used to measure the internal quality of fruit and vegetables, and these have been used to sort fruit into different fruit maturity and quality classes. This segregation improves the consistency of fruit quality in each batch.

A non-destructive technique using the “Kiwifirm” device (Plant and Food Research, New Zealand) has been shown to be useful in identifying the maturity stage of sapota fruit, predicting the quality at ripening stage and also the time required for the fruit to ripen (Aziz et al. 2001). “Kiwifirm” measures the deceleration of a tiny hammer that impacts the surface of the fruit via a small non-bruising and non-penetrating tip. An in-built processor records the resulting collision, analyzes the waveform, and displays a value on a digital display. This technique is non-destructive and allows the testing of individual fruits, as well as
repeated testing of the same fruit. This could be applied to predict which fruit are going to ripen during storage and to reduce inconsistent ripening within a batch (Aziz et al. 2001). However, more research is needed to develop this technique. Moreover, there is a need for more advanced grading techniques to improve the sorting of high-quality attributes of the fruit. For example, the use of a non-destructive technique, such as applying impact response using Fruit Firmness 1 (FF1), has been used to assess and predict internal quality and storage life of ‘Subang’ sapota (Ibrahim 2007). Sapota fruit could be successfully sorted into classes with different storage periods, and fruit for immediate sale (eating ripe-soft) could be identified separately from those that needed additional ripening/storage (e.g., 1–3 more days storage at 12°C) to ensure consistent eating quality. The prediction and classification of fruit using non-destructive methods will guarantee fruit quality in different markets and limit postharvest losses in the supply chain (Ibrahim 2007).

The use of an “electronic nose” had been successful in detecting the aroma of sapota fruit, using four sensors during the ripening process, with the aim of classifying fruit for further sorting processes (Karyadi et al. 2012). Principal component analysis showed that it was possible to classify fruit into unripe, ripe, and overripe maturity stages (Karyadi et al. 2012). Other non-destructive measures, such as estimates of the composition of sugars in immature and mature sapota fruit, using nuclear magnetic resonance techniques, have been demonstrated (Chaughule et al. 2002). Sugars accumulated in sapota fruit during development could be clearly evaluated, but this technology is highly complex and expensive.

X. PROCESSING

As the consumption of processed fruit products is becoming popular, the role of processing industries is becoming increasingly important in horticulture. Processing allows for the utilization of otherwise waste sapota fruit which do not meet fresh fruit consumer or market expectations. Of all the sapota fruit produced in India, nearly 30% is wasted due to incorrect postharvest handling, transportation, and storage (Ganjyal et al. 2005). The use of processing technologies can potentially utilize this waste and add value.

Minimally processed sapota is becoming popular, but rapid fruit softening and discoloration are significant problems which reduce shelf-life. Post-cutting applications of CaCl₂ have been shown to maintain fresh
weight and firmness and to delay color changes of treated ‘Malay’ sapota. However, at high concentrations of CaCl$_2$ there was evidence of the development of a deleterious white scale covering the cut surfaces (Poonsawat et al. 2007). Moreover, Purba (2011) showed that coating with 0.5% glucomannan, and additional modified atmosphere packaging using stretch film, was the optimum treatment for the storage and quality maintenance of fresh-cut ‘Sukatali ST1’ fruit.

Milky white latex that is produced from unripe sapota fruit forms the base for making chicle, which is commercially produced in South East Mexico, Guatemala, and Belize. Chicle is also obtained from latex from the bark of sapota trees, and is the main ingredient of chewing gum (Ahmed et al. 2011). Mixed jams are also produced from mature sapota fruit and provide a valuable source of material for the manufacture of industrial natural fruit jellies (Ganjyal et al. 2003; Hiwale 2015). Dried sapota powder is also rich in vitamins, carbohydrates, fibers, and proteins (Jangam et al. 2008), and can be used as a fiber supplement. Dehydration has been identified as a cost-effective and viable method for producing a wide range of products for the food industry (Ganjyal et al. 2005). Drying removes the moisture from fresh sapota fruit and can be used to preserve sapota slices for long periods of time (Divya et al. 2014). Several drying methods have been examined for fresh sapota fruit, including convection and vacuum oven drying, solar, forced-air, and forced-hot air drying. The highest recovery of soluble solids content, acidity, ascorbic acid and overall quality was obtained from sapota fruit when dried at 65 °C (Ganjyal et al. 2005). The dried powder from vacuum drying was shown to be of superior quality to that obtained from convensional drying (Ganjyal et al. 2005). Padmini et al. (2005) also showed that the moisture content of sapota fruit can be decreased from 76% to 10% within 76 h by solar drying, with time savings of 27% compared to passive sun drying. They further showed that the drying rate of unpeeled and whole fruit was lower than in peeled and thinner sliced fruit (Padmini et al. 2005). Other studies have indicated that the drying of whole fruit with peel was not possible (Jangam et al. 2008). Kumar et al. (2016) dried sapota fruit using a solar tray dryer and hot-air cabinet dryer at drying air temperatures of 80 °C, 100 °C and 120 °C, and showed that the best overall results were obtained using hot-air drying at 80 °C.

Osmotic dehydration is a commonly accepted method for the partial removal of water by submersing fruit in sugar/salt solution (Patil et al. 2014). The osmotic dehydration process of mature sapota fruit was optimized for water loss and sugar gain (Patil et al. 2014), where the optimum conditions were found to be a treatment of 47 °C with sugar
concentration of 55.5 °Brix for a total immersion processing time of 167 min. Rodrigues et al. (2009) studied the effects of ultrasound and ultrasound-assisted osmotic dehydration on fresh sapota tissue, where samples were immersed in distilled water and subjected to ultrasonic waves for 10, 20 and 30 min. The osmotic solution used was prepared by mixing food-grade sucrose with distilled water to give concentrations of 35 and 70 °Brix. Changes in sapota cell structure could be induced by both methods, where the formation of microscopic channels following ultrasound treatment occurred chiefly through the breakdown of dense cells, which helped in the dehydration process. The application of ultrasound-assisted osmotic dehydration resulted in major changes in the tissue structure of the fruit, with consequent increase in effective water diffusivity, because of the formation of microscopic channels and cell rupture (Rodrigues et al. 2009).

Fruit bars have become increasingly popular for their convenience. The preparation of fruit bars includes fruit purées and other ingredients, along with additives such as pectins to increase physico-chemical and sensory characteristics (Salleh et al. 2016). Increasing hardness, adhesiveness, and chewiness of sapota fruit bars was correlated positively with pectin concentration. The color (hue) of the fruit bar also increased as a result of high pectin content (3%), which suggests that pectin can be added as a stabilizer to extend shelf life, and to improve the texture of sapota fruit bars (Salleh et al. 2016).

Nectar is another value-added product which can be prepared from sapota fruit. Relekar et al. (2016) showed that nectar prepared with 25% juice and 18 °Brix SSC had the highest overall acceptability. Sapota wine is another alternative use for sapota fruit. Pawar et al. (2012) showed that the clarified juice of half ripe, ripe and over-ripe fresh sapota fruit could be used for preparing commercially acceptable wines that may be prepared from pulp with further pressing (Pawar et al. 2012).

XI. SUMMARY AND FUTURE PROSPECTS

Sapota is a nutrient-rich fruit which is widely grown in tropical areas. The fruit can be eaten fresh or processed. While there are numerous commercial cultivars, further improvements in fruit quality attributes, such as reduced softening and resistance to postharvest pathogens, would improve the production and quality of sapota fruit available to farmers and consumers around the world. Successful research and development in India has led to new sapota cultivars with improved
storage, transport, and marketing characteristics. This example has significant applications to other growing regions with different agronomic and postharvest challenges. Sapota fruit are very perishable, with a strong climacteric ripening behavior that requires careful handling after harvest to allow transport to distant markets at optimum quality. Both pre- and postharvest factors such as plant nutrition, storage conditions, and packaging all influence the postharvest quality and shelf life of sapota fruit. However, there needs to be a systematic investigation of different pre- and postharvest treatments and management practices to effectively manage postharvest physiological disorders and diseases of sapota fruit, and to establish correct treatments to ameliorate postharvest handling problems. Numerous maturity indices have been considered, including color and days from full bloom to maturity, but more robust techniques need to be developed.

Although sapota fruit ripening has been physiologically described, few studies have been performed of genetic differences and enzymatic changes that occur during ripening, such as cell wall pathogenesis-related enzymes and antioxidant enzymes. There are also significant opportunities to study the associated genes, proteomics and other molecular approaches to investigate the mechanisms of ripening, senescence and resistance to chilling injury and diseases in sapota fruit.

Cold storage is effective in extending postharvest life, but more systematic research is needed to confirm the ideal temperature for different cultivars and different growing conditions. In addition, complementary treatments such as the use of 1-MCP and calcium application should be developed to prolong the postharvest life of the fruit. The use of modified and controlled atmospheres, especially the use of MAP under refrigeration, have shown promising results for postharvest handling and storage, but further research is needed to establish appropriate commercial handling conditions. The establishment of practical postharvest handling and storage techniques will benefit the distribution of sapota fruit onto world markets, where robust export protocols and handling techniques are required to meet market access requirements and retail demands.

Sapota fruit can also be processed into various types of food products. The development and application of new food processing technologies, such as high-pressure hydrostatic processing, will assist new product development and the utilization of otherwise waste fresh sapota. Although sapota fruit is popular in many tropical countries, it is still only a specialty fruit in many parts of the world. Nevertheless, because of its sensory appeal and high nutritional status, sapota has the potential to increase in popularity, with the continuous supply of nutritious,
high-quality fruit onto world markets. Consumer awareness of the fruit and more detailed clinical trials into human health benefits would also increase its awareness and consumption.

LITERATURE CITED


4. SAPOTA (MANILKARA ACHRAS FORB.)


