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A Review of physiological and biochemical changes related to ripening along with post-harvest handling and treatments of Sapota

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Abstract
Sapota is a tropical evergreen fruit-bearing tree. In India, it is commonly known as Chikoo. India is one of the largest producers of sapota in the world. It is very delicious. Apart from the delicious nature, the fruits possess nutritive as well as medicinal properties. But due to shorter shelf life, it could not be stored for a long period. Post-harvest losses are very much high in the case of sapota. Proper post-harvest management that includes both pre-harvest and post-harvest treatments are required to increase the post-harvest life as well as to maintain the quality of the fruits. Pre-harvest treatments such as application of different chemicals i.e. during vegetative as well as reproductive stage and post-harvest treatments such as pre-cooling, chemicals, heat treatments, waxing or coating, cold storage, irradiation, modified atmosphere packaging (MAP), controlled atmosphere storage, etc are used to increase the shelf life. This article gives a brief review of physiological and biochemical changes that occur during ripening of sapota and also explores the pre-harvest and post-harvest treatments adopted to enhance the shelf life of sapota.

Keywords: Sapota, post-harvest management, ripening, map, controlled atmosphere storage, irradiation, cold storage, waxing, pre-cooling

Introduction
Sapota (*Achras sapota* L. syn *Manilkara achras* Mill.), a tropical evergreen fruit-bearing tree is commonly known as Chikoo in India. It is also popularly known as Sapodilla Plum, Chico, Zapote, Nispero, etc. in different regions (Yahia and Gutierrez-Orozco, 2011) [63]. It belongs to the family Sapotaceae and believed to have originated in Southern Mexico or Central America (Siddiqui *et al*., 2014) [51]. The estimated area under sapota cultivation in India is about 97 thousand hectares and production is about 1176 thousand metric tonnes (Anonymous, 2018) [2]. Gujrat and Karnataka contribute about 28.19% and 27.25% of the total production (Anonymous, 2017-18) [1]. It is rich source of sugars (12–18 %), proteins (0.7 g/100 g), ascorbic acid (6.0 mg/100 g), phenols (15.35 mg gallic acid equivalent/100 g), carotenoids (1.69 mg b-carotene/100 g), and minerals, for example, phosphorous (27 mg/100 g), calcium (28 mg/100 g), iron (2.0 mg/100 g), potassium (193 mg/100 g), copper (0.086 mg/100 g), etc. (Ugalat *et al*. 2012) [56]. India is one of the largest producers of sapota in the world. Maharashtra, Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, West Bengal are the major sapota growing states in India (Radha and Mathew, 2007) [37].

One of the major postharvest issues is quick ripening and faster senescence of edible ripe fruit. The storage life of sapota fruit is exceptionally short-lived and can only be stored for 7-8 days under ordinary conditions after harvest (Reddy, 2018) [42]. The shelf life of sapota fruits could be possibly extended by reducing the rate of respiration, loss of water through transpiration, and microbial infection which is mostly caused by the species of *Botryodiplodia, Pestalotiopsis, Phytophthora,* and *Phomopsis* (Siddiqui and Dhua 2010; Siddiqui *et al*. 2013) [50, 51]. According to Gadgile *et al*. (2010) [13], postharvest fungal diseases of sapota are black mould rot (*Aspergillus niger*), Green mould rot (*Penicillium spp*) and Rhizopus rot (*Rhizopus oryzae*). As soon as the fruits reached the climacteric peak the shelf life of the sapota fruit deteriorates. Heavy post-harvest losses to the extent of 20-30 percent suffered by sapota in India (Salunkhe and Desai, 1984) [45]. Khurana and Kanawjia (2006) [19] stated that due to the short shelf-life of sapota fruits, about 30-35 percent of fruits perish as post-harvest losses during harvesting, storage, grading, transportation, packaging, and distribution thus incurring a precious loss in India.

There are numerous varieties related to sapota. Sapota cultivars are distributed throughout our country. The commercially cultivated varieties grown in different regions are mentioned in Table 1.

Table 1: Commercially cultivated varieties grown in different regions of India (Shirol *et al*., 2019) [49]

State	Cultivars
Andhra Pradesh	Pala, Kirthabarthi, Singapore, Cricket Ball, Dwarapudi, Gutti, and Jonnavalasa.
Gujarat	Kalipatti, Bhuripatti, Pilipatti, Dhola Diwani, Jhumakhia, and Cricket Ball.
Karnataka	Kalipatti, Cricket Ball, Pala, Kirthabarthi, DHS-1, and DHS-2
Maharashtra	Kalipatti, Cricket Ball and Murabba
Tamil Nadu	Gutti, Kirthabharti, Pala, Co-1, Co-2, and PKM-1
Telangana	Kirthabhathi, Pala, Cricket Ball and Kalipatti
Others	Cricket Ball, Round, Oval and Bramasi

Use of sapota fruits in various aspects

- Fruit of sapota contains Vitamin E, A, and C which helps to keep skin healthy. The milky sap of the sapota plant helps in clearing worst and fungal growth on the skin. The oil extracted from seeds of sapota helps in treating hair fall due to seborrheic dermatitis. (Parle and Preeti, 2015) [32].
- Sapota tree possesses latex called ‘chicle’ which is considered as the main ingredient of chewing gum (Morton, 1987) [31]. He also added young fruit contains tannins that are used to stop diarrhea.
- Sapota can be used for the production of Value-added products like squash, jam, candy, sapota cheese, sapota candy, sapota biscuit, sapota ice cream, sapota shrikhand, nectar, toothy – fruity, etc (Jadhav, 2018) [15].

Maturity index and harvest

Sapota fruits generally mature in about 240 to 270 days after flowering (Radha, 2014) [36]. Fruits do not show green tissue or latex when scratched with a fingernail on the attainment of the harvestable stage (Miranda *et al*. 2004) [30]. When the fruits attain physiological maturity it shed off brown scaly external material and becomes smooth (Lakshminarayana 1980) [21]. According to Kute and Shete (1995) [65], sapota fruit is considered mature when its surface becomes smooth, shining potato color, and rounded styler-end. The erratic flowering habit of Sapodilla and the presence of fruit at all stages of development on the tree make it hard to decide the ideal time for harvest (Lakshminarayana, 1980) [21]. The matured fruits are harvested by handpicking or with the help of a special harvester which has a round ring with a net bag fixed onto a long bamboo. Twisting or cut fruit stalk near the point of attachment with fruit clipper. Ladders and baskets could also be during harvesting and the peduncle is cut with the help of knife or scissors. Selection can be based on the size and maturity of the fruits. Fruits with deterioration or mechanical injury are discarded (Yahia, 2004) [60]. Fruits harvested at a premature stage may not ripen and are usually low in sweetness, high in astringency, with a rather unappealing alcoholic aftertaste. Peiris (2007) [34] stated that the poor quality of prematurely harvested fruits is due to the formation of pockets of coagulated latex. Unripe fruits are highly astringent and contain large amounts of leucoanthocyanidins. On the other hand, fruits harvested late soften quickly resulting in high spoilage during handling and transport.

Physiological and biochemical changes during ripening

Respiration and Ethylene evolution

The sapota fruit shows the typical climacteric pattern of respiration (Broughton and Wong, 1979; Lakshminaryana and Subramanyam, 1966) [7, 22]. Sapota can be categorized as horticultural produce with an extremely high rate of Carbon dioxide evolution (Kader, 2002) [17]. Mangaraj and Goswami (2009) [28] stated that sapota generally shows moderate respiration rates at 5 °C (10–20 mg CO_2 kg^{-1} h^{-1}), and high levels of ethylene production, that is, higher than 100 µl C_2H_4 kg^{-1} h^{-1} at 20 °C. Sapota exhibits a very high rate of ethylene evolution (>0.018 nmol kg^{-1} s^{-1}, Kader, 2002) [17].

Total soluble solids (TSS)

Quality of fruits is determined by Total soluble solids (TSS) of fruits which include 90 percent of sugars and 10 percent of minerals content and acids. An increase in TSS during storage might be associated with the hydrolysis of starch in soluble sugars (Ishaq *et al*., 2009) [66]; Hoda *et al*., 2000 [69]) and decrease in TSS during subsequent storage is due to the utilization of sugars in the respiration process. Kumar *et al*., (2016) [67] also observed an increase in total soluble solids during storage in sapota fruits. An increase in the TSS content is observed in Sapota fruits from harvest until ripening and later a decrease in TSS as fruits started senescing (Tsomu *et al*., 2015) [68].

Firmness and enzyme activity

According to Qiuping *et al*. (2006) [35], fruit softening and ripening of sapota is related to a reduction in fruit firmness, where firmness can decline from 60 N in the early stages of ripening to 8 N in ripe fruit. There is a decrease in flesh firmness rapidly at the peak of the respiratory climacteric and then did not change significantly during further storage at ambient condition storage (Vishwasrao and Ananthanarayan, 2016) [58].

Maturation involves the synthesis of hydrolytic enzymes, i.e. α-amylase, β-amylase, and starch phosphorylase, which ends up in an accumulation of inverted sugars and polygalacturonase involved in softening of the tissue and accelerating changes during ripening (Vishwasrao and Ananthanarayan 2016) [58]. Enzymes related to enzymatic browning are Polyphenol oxidase and peroxidases (Barberan and Espin 2001 [4]; Vishwasrao and Ananthanarayan 2016 [58]) in fruit and vegetables, and during ripening their activities increases and afterward gradually decrease with senescence (Malhotra *et al*. 2009) [27].

Physiological Loss of Weight (PLW)

Haard and Salunkhe (1975) [70] stated that PLW is mainly due to evaporation and transpiration, respiration, and various physiological processes occurring in fruits after harvesting of fruits. An increase in PLW (1.67% to 6.24%) is observed in sapota fruits with the advancement in storage period i.e. 0-24 days (Kumar *et al*., 2016) [67].

Specific Gravity

According to Pawar *et al*., (2011) [71], different stages of ripening influenced the specific gravity of sapota fruits. Specific gravity increased from mature, half-ripe, ripe to overripe sapota fruits. An increase in specific gravity indicating that a decrease in weight of fruit was lesser than the corresponding decrease in its volume.

Sugars

Carbohydrates are one of the important constituents of sapota fruit (Sumathi and Shivashankar, 2017) [54]. There is a change in concentrations of individual sugars during ripening, where levels of sucrose show the highest increase during ripening, followed by glucose and fructose (Yahia and Gutierrez-Orozco, 2011 [62]; Sumathi and Shivashankar, 2017 [54]).

Phenolic compounds

It is observed that the concentrations of phenolic compounds decline during ripening (Camargo *et al*. 2016 [8] and Lim 2013 [25]). According to Rastegar (2015) [38], the total phenolic content has been observed to range from 2.7 mg of gallic acid equivalents g^{-1} Fruit Weight at the early stages of ripening down to 1.0 mg gallic acid equivalents g^{-1} Fruit Weight in the final stages of ripening.

Organic Acids

Sumathi and Shivashankar (2017) [54] stated that the major organic acids found in mature sapota fruit are malic (18.25 mg g^{-1} Fruit weight), citric (8.30 mg g^{-1} Fruit weight) and tartaric (2.69 mg g^{-1} Fruit weight). Other organic acids, for example, gluconic, fumaric, and oxalic acids have only been identified at the development and ripening stage (Das and De, 2015) [10]. The reduction in levels of titratable acidity in the fruit has been observed from 0.48% to 1.36% in the initial stage of fruit development to lower levels (0.11–0.41%) when the fruit attains the ripe stage (Yahia and Gutierrez-Orozco, 2011) [62]. According to Brito and Narain (2002) [6], 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.

Minerals

According to Hamza *et al*. (2013) [14], sapota fruit contains high concentrations of iron (14.2 μg g^{-1} Dry Weight), manganese (1.5 μg g^{-1} Dry Weight), copper (1.7 μg g^{-1} Dry Weight), and zinc (1.0 μg g^{-1} Dry Weight). There are considerable differences in the concentrations of minerals between different nutrition studies, but these may be the result due to various environmental and other growing conditions.

Pre-harvest treatments

According to Siddiqui *et al*., (2014) [52], pre-harvest sprays with different chemicals are often used to modify the ripening process of different fruits or to transform the maturity of a particular attribute with an influence on storage potential or commercial appeal.

Application of Cycocel (400 and 200 ppm) at fruit bud differentiation stage increases the physical attributes such as Length, diameter, weight, the volume of fruit, pulp thickness, pulp as well as peel weight of sapota fruits. Whereas the application of naphthalene acetic acid (NAA- 100 ppm) at flowering and pea stage proved to be the best for all the physical characters of fruit as compared to gibberellic acid (GA- 50 ppm). Shailendra and Dikshit (2010) [48] stated that total soluble solids (TSS), sugars, and ascorbic acid were increased with the application of Chlormequat (CCC) whereas acidity of fruits was decreased. According to Bhalerao *et al*. 2010 [5], preharvest application of calcium chloride 1.0 percent reduced PLW percent during storage and improved Physico-chemical qualities like shelf life, firmness, and total sugar content. Spraying of Calcium delays the ripening process by reducing respiration rates or ethylene production. It also delays the incidence of postharvest decay. Significant changes in antioxidant capacity or the content of antioxidant compounds such as phenols and ascorbic acid have also been found in some fruits (Lara, 2013) [24].

Lakshminarayana and Subramanyam (1967) [23] found that fruit ripening can be delayed by spraying with a solution of 2,4-D i.e.100 ppm or 2,4,5-T i.e. 25 ppm or maleic hydrazide (500–1,000 ppm) in sapota. Preharvest application of Carbendazim and Topsin-M retarded the ripening process and increases shelf life when dipped in the solution (Raut *et al*. 2006) [40]. Lakshmana and Reddy (1995) [20] observed that the application of Gypsum at 0, 1, 2, or 4 kg/tree to fruiting sapota cv 'Kalipatti' enhanced the storage quality of fruits in terms of appearance, aroma, pulp color, taste, firmness, and texture.

Post-harvest treatments

Sapota fruits are climacteric in nature which results in quick ripening of fruits. To maintain the quality and to allow proper marketing, sapota needs adequate postharvest management technologies starting from harvesting to the ultimate consumer. To increase the shelf life of the fruits there is a need for post-harvest treatments and few of the treatments are discussed below.

Pre-cooling

According to Raut (2002) [39], still air pre-cooling of sapota fruits showed a maximum shelf life of 7 days and maximum overall acceptability along with minimum weight loss. Gade (2003) [12] reported that forced-air pre-cooling is required for about 18-23 minutes at 15°C to obtain good appearance and quality.

Chemicals

It is observed that Sapota fruits can be stored safely for a longer duration at ambient temperature condition as well as cold storage with the application of certain ripening retardant postharvest treatments, for example, fruit coating with resin (Waxol), gibberellic acid (GA_3), calcium chloride, potassium permanganate, and chlormequat at a required concentration (Singh and Borase 2003) [23]. Treatment with 2,4-D (4 ppm) and GA3 (200) ppm exhibited the longest shelf life of 32 and 31.33 days, respectively, at 12°C observed by Madhavi *et al*. (2005) [26]. Sapota fruits treated with 50 and 100 ppm of silver nitrate and gibberellic acid, respectively, and then packed in polyethylene bags of 200 gauge with 20 % ventilation showed an increase in storage life with minimum degradation (Sahoo and Munsi 2004) [44]. Gibberellic acid can regulate the physiological process of the fruit ripening by delaying the development of pigment changes and softening of fruits (Siddiqui *et al.* 2013) [51].

Madhavi *et al.* (2005) [26] observed that the application of ethephon enhances the ripening process by 1 day and decreases phenolic compounds. They also reported that fruits dipped in an aqueous solution of ethrel (1,000 ppm for 5 min) showed uniform ripening, higher TSS, and total sugars content in sapota cv. Pala. According to Dhua *et al.* (2006) [11], the ripening of sapota fruits cultivar Kalipatti was reduced by utilization of ethylene absorbents i.e. celite–$KMnO_4$ in sealed polyethylene bags as compared to those of silica gel–$KMnO_4$ and vermiculite– $KMnO_4$. Calcium treated fruits of sapota with a higher concentration remained firmer and high TSS as compare to fruits treated with lower concentration (Dhua *et al.* 2006) [11].

Heat treatments

Hot water treatment with different temperature and holding time were also found significant for maintaining the quality of sapota fruits during storage. Dipping of sapota fruits in hot water at a temperature of 50°C for 5 minutes enhanced the shelf life of fruits (cv. Co-1 and 2) up to 14 days with very less weight loss i.e.13% and delayed the ripening process. It is also observed that the quality parameters such as total soluble solids, total sugars, and sugar: acid ratio were also maintained with this treatment (Vijayalakshmi *et al*. 2004) [54]. Yahia and Ariza (2003) [64] reported that hot air treatment increases the larvae and egg mortalities at 43ºC for 120 minutes. They also added that lower temperature treatment i.e. 40ºC for 120 minutes was effective in causing the mortality of larvae but not of eggs. Heat treatment at 43ºC for 120 min did not cause any fruit injury and also resulted in a minimum loss in firmness, the mass of fruits, and color. But they also mentioned that hot air treatments at a temperature of 50ºC can cause fruit injury and losses in fruit mass, texture, and color.

Waxing or coating

Sarkar *et al*. (1995) [47] suggested that the physiological loss of weight of fruit is reduced when waxol is applied and maintain comparatively higher TSS, total sugars, reducing sugar content, and acidity. It is observed that fruits treated with 6 percent wax emulsion along with packaging the treated fruits using 200 gauge polyethylene bags containing ethylene and CO_2 absorbents had a shelf life of 45 days at a temperature of 12°C which is 10 days more than that of control (Chundawat, 1991) [9] reported. However, coating with candle wax did not increase the storage life of sapota fruits but the appearance of the fruits is (Arevalo Galarza *et al*. 1999) [3].

Cold storage

The rate of change of chemical constituents was found to be slower in fruit stored at 12°C as compared to fruits stored at 15°C and ambient condition. It is observed that most of the varieties of sapota fruit can be stored at a temperature of 12°C for a long period with good edible quality (Patel *et al*. 2010) [33]. According to Roy (2001) [43], there is an increase in the shelf life (14-21 days) of sapota fruits when the fruits are stored at a temperature of 12°C and he also observed that there is a reduction of physiological weight loss of the fruits during storage.

Irradiation

Yadav *et al.* (2013) [59] observed that treating the sapota fruits with gamma irradiation with a combination of different plant growth regulator increases the shelf life of the fruits. They also reported that these treatments help in lowering physiological loss in weight and maintain maximum firmness during storage. It also found that there is an increase in total soluble solids, sugars, and acidity.

Modified atmosphere packaging (MAP) and Controlled atmosphere storage

According to Joshua and Sathiamoorthy (1993) [16], packaging of sapota fruits in polyethylene film increases the shelf life. They also observed that there was a decrease in spoilage and delay in the ripening process when the fruits were packed in polyethylene bags of 100 gauge thickness with 0.4 % perforation as compared to 150 and 200 gauge polyethylene bags. Kannan and Susheela (2003) [18] suggested that the waxing of sapota fruits before vacuum packaging in polyethylene bags (200 gauge thickness) maintained most of the quality parameters and the shelf life of the fruits increased up to 3 weeks when vacuumed packed.

In the case of controlled atmosphere storage, it is observed that storage life of sapota fruits at room temperature increased from 13 to 18 days with 5 % CO_2, 21 days with 10 % CO_2, and up to 29 days with 20 % CO_2 (Yahia, 1998)[61]. Manzano (2001) [29] revealed that fruits of sapota stored at a temperature of 15 ± 2°C along with treatment 5 % CO_2, 5.6 % O_2, and 89.3 % N_2 for 4 weeks. He also added that the soluble solids content of fruits was between 15.65 and 22.80 percent when treated with CO_2 at 15 ± 2°C temperature, pH value between 5.38 and 6.83, and titrable acidity between 0.05 and 0.38 %. Fruits maintained good quality during the 3rd week of storage.

Packaging, transportation, and marketing of sapota

Sapota fruits are highly perishable and mishandling causes about 25-40% of wastage of produce. Therefore, proper packaging during the transportation is very much essential. Sapota fruits which are marketed locally are packed with baskets made up of bamboo padded with straw. Straw is used as padding materials to reduce bruises during transportation and also promotes even ripening of fruits. For long-distance transportation of fruits, corrugated trays are also used for packaging. The popular mode of transporting the fruits from orchard to market is trough road transportation with the help of trucks, lorries, or pick up vans (Reddy, 2015) [41].

Conclusion

Sapota is one of the important fruit crops in India. Places like Gujrat, Karnataka, Tamil Nadu share the maximum part in terms of production. Most of the farmers' livelihood is dependent on the production of sapota. Therefore, proper management practices after the harvest of the crops should be suggested to the farmers so that they will become aware of the practices and implement them. In this article, we discussed different pre-harvest as well as post-harvest practices which could be done for increasing the shelf life of the fruits. Increasing self-life is very much important in India because most of the produce is transported to a distant market for selling and people want to buy fresh produce every day. Recent trends such as modified atmosphere packaging, controlled atmospheric storage, irradiation, etc. are widely adapted but there is a need for proper dissemination of process to every part of the country. Most of the people who are involved in post-harvest management have very little knowledge about these methodologies to increase shelf life. Proper post-harvest management plays a vital role in reducing losses. Further research on post-harvest management of sapota is still needed to increasing shelf life without affecting the quality of the produce.

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