1. INTRODUCTION

Sapota (*Manilkara acharas* (Mill.) Fosberg), an evergreen, delicious tropical fruit crop of the world belongs to the family Sapotaceae. Sapota is commonly named as chiku, sapodilla and is mainly cultivated in India for its fruit value. In the regions of South-East Mexico, Guatemala and other parts of the world, it is commercially grown for the production of *chicle* which is a gum-like substance obtained from the latex, commonly used for the preparation of chewing gum. The fruit can be used as fresh and also processed. Sapota is one of the important popular fruit crops in the states of Gujarat, Maharashtra, Karnataka, Tamil Nadu, Andhra Pradesh, Telangana and Kerala. The fruits are recommended to adult patients ailing from tuberculosis and children from the primary complex.

2. COMPOSITION AND USES

Sapota, a highly nutritious fruit crop fortified with a wide range of beneficial components such as dietary fiber, fructose, glucose, sucrose, vitamins, minerals, diverse phytochemicals, fatty acids, and polyamines (Table 1,2). Fruit contains high concentrations of minerals such as potassium, calcium, iron, copper, zinc and phenolic components (Mund *et al.* 2016; Sumathi and Shivashankar, 2017). Phenolic compounds from sapota fruit have been shown to possess a range of anticancer activities. The fruit pulp contains sapotin (a glucoside used in medicine to reduce fever), saponin, fixed oils, and other bitter alkaloids (Madhav and Khurana, 2011). Sapota fruit is considered to be a high source of antioxidants as they contain over 3000 mg⁻¹ ascorbic acid equivalent antioxidant capacity (AEAC) per 100 g fresh sample (Shui *et al.* 2004; Lim, 2013).
Table 1: Nutritional value of Sapota fruit and juice in 100g edible portion

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Value</th>
<th>Constituent</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>78.00g</td>
<td>Pantothenic acid</td>
<td>0.2528g</td>
</tr>
<tr>
<td>Protein</td>
<td>0.44g</td>
<td>Vitamin B-6</td>
<td>0.037mg</td>
</tr>
<tr>
<td>Total lipid (fat)</td>
<td>1.10g</td>
<td>Folate</td>
<td>14 µg</td>
</tr>
<tr>
<td>Ash</td>
<td>0.50g</td>
<td>Vitamin A</td>
<td>60IU</td>
</tr>
<tr>
<td>Total dietary fiber</td>
<td>5.3g</td>
<td>Palmitic acid</td>
<td>0.1g</td>
</tr>
<tr>
<td>CHO</td>
<td>19.96g</td>
<td>Stearic acid</td>
<td>0.094g</td>
</tr>
<tr>
<td>Calcium</td>
<td>21mg</td>
<td>Oleic acid</td>
<td>0.521g</td>
</tr>
<tr>
<td>Magnesium</td>
<td>12mg</td>
<td>Linoleic acid</td>
<td>0.011g</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>12mg</td>
<td>Tryptophan</td>
<td>0.005g</td>
</tr>
<tr>
<td>Potassium</td>
<td>193mg</td>
<td>Leucine</td>
<td>0.024g</td>
</tr>
<tr>
<td>Sodium</td>
<td>12mg</td>
<td>Lysine</td>
<td>0.039g</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.10mg</td>
<td>Arginine</td>
<td>0.017g</td>
</tr>
<tr>
<td>Copper</td>
<td>0.086mg</td>
<td>Aspartic acid</td>
<td>0.032g</td>
</tr>
<tr>
<td>Iron</td>
<td>0.80mg</td>
<td>Glutamic acid</td>
<td>0.038g</td>
</tr>
<tr>
<td>Selenium</td>
<td>0.6µg</td>
<td>Proline</td>
<td>0.036g</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>14.7mg</td>
<td>Lycopene</td>
<td>41.93 (µg 100g⁻¹ DW)</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>0.020mg</td>
<td>Total phenolic</td>
<td>13.5 (mg GAE 100g⁻¹)</td>
</tr>
<tr>
<td>Niacin</td>
<td>0.200mg</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Yahia and Gutierrez-Orozco, 2011; Da Silva et al. 2014; Madani et al., 2018

Table 2: Chemical composition of sapota fruit juice

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total soluble solids</td>
<td>20.68%</td>
</tr>
<tr>
<td>Reducing sugar</td>
<td>9.89%</td>
</tr>
<tr>
<td>Total sugar</td>
<td>11.06%</td>
</tr>
<tr>
<td>Acidity (citric acid)</td>
<td>0.16%</td>
</tr>
<tr>
<td>Protein</td>
<td>312.5mg /100g</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>10.52mg /100g</td>
</tr>
</tbody>
</table>
3. ORIGIN, HISTORY AND DISTRIBUTION

Sapota is considered to be originated from Mexico (specifically the Yucatan Peninsula), Central and South America and has been introduced throughout tropical America, the West Indies, the Bahamas, Bermuda, the Florida Keys, and the southern part of the Florida Mainland, and the Philippines. Today, its cultivation has spread all over the tropical belt and is being grown as a major commercial crop in India, Sri Lanka, West Indies, Philippines, Indonesia and Malaysia. In India, it is not exactly known when sapota was first introduced but its cultivation was taken up for the first time in Maharashtra in 1898 in a village named Gholwad. India is considered to be the largest producer of sapota in the world.

Recently, as per 2\textsuperscript{nd} advance estimate, the area under sapota in India during 2019-2020 was 83,000 ha with a production of 10.03 lakh tones (https://pib.gov.in/Pressreleaseshare.aspx). The important sapota growing states are Maharashtra, Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, Kerala, Uttar Pradesh, West Bengal, Punjab, and Haryana. Recently our country has made a beginning in export to Middle East countries. The state-wise area, production and productivity status under sapota in India given with the available data given in Table 3.

Table 3: State-wise area, production and productivity of sapota in 2017-18

<table>
<thead>
<tr>
<th>S. No.</th>
<th>State / UTs</th>
<th>Area (in’000 ha)</th>
<th>Production (in ‘000 MT)</th>
<th>Productivity (in MT/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Andhra Pradesh</td>
<td>10.09</td>
<td>131.46</td>
<td>13.03</td>
</tr>
<tr>
<td>2</td>
<td>Chattisgarh</td>
<td>0.38</td>
<td>1.79</td>
<td>4.76</td>
</tr>
<tr>
<td>3</td>
<td>Gujarat</td>
<td>29.55</td>
<td>326.36</td>
<td>11.04</td>
</tr>
<tr>
<td>4</td>
<td>Haryana</td>
<td>1.69</td>
<td>14.65</td>
<td>8.67</td>
</tr>
<tr>
<td></td>
<td>State</td>
<td>Fruit Production</td>
<td>Fruit Yield</td>
<td>Gross Value</td>
</tr>
<tr>
<td>---</td>
<td>------------------------</td>
<td>------------------</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td>5</td>
<td>Himachal Pradesh</td>
<td>0.05</td>
<td>0.07</td>
<td>1.50</td>
</tr>
<tr>
<td>6</td>
<td>Karnataka</td>
<td>25.31</td>
<td>315.38</td>
<td>12.46</td>
</tr>
<tr>
<td>7</td>
<td>Kerala</td>
<td>0.16</td>
<td>0.48</td>
<td>3.07</td>
</tr>
<tr>
<td>8</td>
<td>Madhya Pradesh</td>
<td>0.23</td>
<td>4.03</td>
<td>17.21</td>
</tr>
<tr>
<td>9</td>
<td>Maharashtra</td>
<td>15.03</td>
<td>134.78</td>
<td>8.97</td>
</tr>
<tr>
<td>10</td>
<td>Odisha</td>
<td>3.36</td>
<td>15.72</td>
<td>4.68</td>
</tr>
<tr>
<td>11</td>
<td>Rajasthan</td>
<td>0.01</td>
<td>0.03</td>
<td>3.00</td>
</tr>
<tr>
<td>12</td>
<td>Tamil Nadu</td>
<td>5.76</td>
<td>169.96</td>
<td>29.50</td>
</tr>
<tr>
<td>13</td>
<td>Telangana</td>
<td>0.83</td>
<td>9.45</td>
<td>11.44</td>
</tr>
<tr>
<td>14</td>
<td>Tripura</td>
<td>0.14</td>
<td>0.88</td>
<td>6.31</td>
</tr>
<tr>
<td>15</td>
<td>West Bengal</td>
<td>4.38</td>
<td>48.2</td>
<td>11.00</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>0.33</td>
<td>2.63</td>
<td>7.90</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>97.29</td>
<td>1175.89</td>
<td>12.09</td>
</tr>
</tbody>
</table>

Source: Horticulture Statistics Division, Department of Agri. & Cooperation

4. TAXONOMY

Sapota belongs to the genus *Manilkara* from the order Ericales of the family Sapotaceae and subfamily sapotoideae. The Sapotaceae is mainly a tropical family which contains 50 genera and 1200 species. Its botanical name is *Manilkara achras* (Mill.) Fosberg (Syn: *Achras zapota* L.). *Manilkara hexendra, Manilkara kauki, Manilkara elengi* are some of the other important species that occur wild in India and have the potential to be used as rootstock. Chromosome number of sapota is, 2n = 26 (X =13).

5. BOTANICAL DESCRIPTION

Plants are tall, spreading/ upright, slow-growing, evergreen in nature bark rough contains milky latex with whorls of horizontal branches produced at regular intervals, dark brown, tree top round/ globose or pyramidal in shape, trunk low branched. All plant part on injury exudes white latex. Leaves simple, alternate, dark green, glossy above, lighter with dense pubescence below, ovate-elliptic to oblong-lanceolate, wedge-shaped (cuneate) to broadly acuminate at both the apices, margin entire, midrib depressed below, thick and prominent below, lateral veins parallel and many, petiole medium thick and long. Flowers axillary and solitary in upper leaf axils and clusters of 2-3 or more in lower leaf axils, pendulous, about 1.5cm in diameter, regular and perfect, pubescence hair like thick and brown, pedicel short
(1-2cm). Calyx brown 6 present in two whorls, outer three united at base and pubescent, inner three are light green, rounded and leathery. Corolla 6, gamopetalous lobed in a single whorl, tubular, longer than calyx, white campanulate about one-third of its length divided into 12 segments which are equal oblong erect and glabrous. Stamens, six perfect and six staminodes, usual places between petals, filaments short, erect obliquely placed on calyx tube, yellowish-brown, four celled, ovary 10 – 12 celled superior, subcaroys style, oval-shaped (subulate) distinctly exerted from the flower before ripening, stigma oblique, disc, or cushion-like growth prominent on the ovary. The fruit is round, globose ellipsoid hanging berry, apex with style remains at stalk end, skin rough, thin yellow-brown (rusty brown) to reddish overlaid by fine scaly matter. Epicarp thin, mesocarp (flesh) is yellowish-brown, granular at skin/ripening develops sweetness flavour and juicy pulp. Seed usually 2-4, oblong, laterally compressed black and brown coloured, separate easily from pulp, hilum distinct.

5.1. Floral biology

Flower buds are borne in the axil of the leaves of current seasons’ growth. The period taken from the emergence of a flower bud to its opening is about 36 days. Flowers open largely between 4.00 and 4.30 am. The flower is protogynous. The style and stigma grow out about 48 hours before flower opening. Anthers dehisce mostly between 8 am and 10 pm on the day of anthesis and become empty by the next morning. The flowers keep fresh for nearly two days. The stigma remains receptive for two days before opening and continues up to 12 hours after opening. The peak receptivity is between 8 am to 10 am.

6. CLIMATIC AND SOIL REQUIREMENTS

Being a tropical fruit crop, it can be grown from sea level up to 1200-meter height. It prefers a warm and humid climate and grows in both dry and humid areas. Areas with an annual rainfall of 125-250 cm are highly suitable. The optimum temperature ranges between 12°C to 36°C. In South India, it is grown on the hills up to 1000 MSL. At higher altitudes, the fruit quality and tree health suffer. Rain or cloudy weather affects fruit set. Under warm (10-38°C) and humid (70% RH) climate, it flowers and fruits throughout the year. However, under subtropics or places of higher elevation like Punjab and Haryana, it gives only one crop from summer flowering in April and May.

The sapota crop can be grown on a wide range of soils but grows best in well-drained, light soils. Trees are especially well adapted to the rocky, highly calcareous soils. Drainage is the most important. There should not be a hardpan in the sub-soil. Deep and porous soils make good growth. The sapota can tolerate the presence of salts in the soil or irrigation water to some extent. If the soil is poor, it is advisable to grow a green manure crop and plough back into the soil to improve its physical and chemical conditions before planting. Plants grow well near the seashore, indicating a good tolerance to sea salt spray. Typical
symptoms of salt stress include marginal and tip necrosis of leaves, leaf browning and drop, stem dieback, and tree death.

6.1. Effect of climate change

Climatic fluctuations tend to alter the change in land-cover patterns at a mixture of temporal and spatial scales. Patil et al. (2015) assessed the compound growth rate of area, production and productivity of sapota and correlated with rainfall and temperature pattern over ten years. With the lowest annual growth rate (3.10%), the crop recorded 1.74% more productivity. There was a major deviation in correlation among the area, production and productivity of sapota with rainfall since most of them were grown under irrigated conditions. On the other hand, productivity with respect to maximum temperature expressed significant correlation evident that enhanced temperature levels influenced positiveness with productivity. According to a survey performed during post-frost season by Bhati et al. (2018) in Bikaner and adjoining areas, it was evident that sapota remains less affected to frost injury.

7. PROPAGATION AND ROOTSTOCK

7.1. Seed propagation

Sapota seedlings are raised for grafting purposes. In Andhra Pradesh, Adam’s apple (Manilkara kauki or Mimusops kauki) is used as a rootstock. The seedling as rootstocks grows quickly and develops a tap root system but shows signs of delayed graft incompatibility by overgrowing the scion. Mahua produces bigger plants but fruits are poor in quality. Of all the rootstocks raised through seeds, rayan or khirni or pala (Manilkara hexandra) is the most suitable rootstock. Sapota can be propagated through seeds, which is the basis of its variability in India.

The different rootstocks used for sapota propagation are sapota seedlings (Manilkara achras); rayan or khirni or pala (Manilkara hexendra or Mimusops hexendra); Adam’s apple (Manilkara kauki or Mimusops kauki); mahua (Madhuka latifolia); mee tree (Bassia longifolia); star apple (Chrysophyllum cainito) and miracular fruit (Sideroxylon dulicificum). Soaking of khirni seeds in cow dung slurry for 24 hours give the maximum germination percentage. Spraying of khirni seedling with GA₃ @ 200 ppm at 3rd and 6th month for enhancing the seedling growth and which will be ready for softwood grafting in 12-13 months. At Gujarat Agriculture University, application of 11.5 g N/m² (Urea 25 g/m²) at the monthly interval from 3rd to 11th month after sowing of rayan seed and GA₃ spray @ 200 ppm at 3, 6 and 9-month-old seedlings produce healthy rootstock.

7.2. Vegetative propagation

Sapota can be propagated by grafting, inarching, layering and cuttings. The layered plants
grow vigorously and the method is cheaper as no rootstock is required. Plants propagated through layering or cuttings establish poorly and are susceptible to wind damage. Hence, both layers and cutting are not followed for commercial propagation.

### 7.2.1. Inarching

It is a commercial method of propagation practiced for over 40 years. The rootstocks are raised in pots. The scion remains attached to the parent tree till the union is complete and if the scion branches are high; the stock plants are hanged on the scion tree or placed on a bamboo platform. Two-year-old potted khirni plants with pencil thickness are suitable for the inarching purpose. Inarching performed in December – January and plants are ready for separation in June – July of next year. In Andhra Pradesh, pala (*Manilkara hexandra*) and Adam’s apple are used as rootstock.

### 7.2.2. Veneer grafting

In this method, the scion is prepared in the form of a wedge with one side slightly longer than the other. An incision is made into the stock at an angle of 20-25 degree and the scion is inserted into the incision. Both are properly tied and sealed at the graft union. After union, the top of the stock plant is cut just above the point of union.

### 7.2.3. Softwood grafting

Commercially sapota is propagated by softwood grafting on rayan seedlings. It is an economically viable, faster, efficient technique for sapota propagation. This method has replaced the earlier method called approach grafting. The sapota when grafted on rayon has initially slow growth but the tree lasts longer. For this method, scions are chosen from young terminal shoots. Softwood grafting carried out in the month of July-August, using khirni rootstock gives 93% success. Grafting operations carried out in May gave maximum graft success in sapota at Karnataka. The technique can be used for raising *in situ* plantation using new growth of rootstock for grafting with activated scion which is prepared in the form of a wedge and inserted in the split end of the new growth of rootstock.

To know the incompatibility of sapota cultivars to softwood grafting and to find out the best time for softwood grafting, two sets of experiments were carried out by Ghosh *et al.* (2010) in West Bengal. The considerable variation of success in softwood grafting among the sapota cultivars was observed. Among the ten cultivars studied, CO-2 showed the highest compatibility with the khirni rootstock to softwood grafting followed by Cricket Ball and DSH-2. There was a total failure in graft-in-take in the cultivars CO-1, DSH-1, and Guthi. Softwood grafting was the highest in sapota when carried out on 1st July (72%) followed by 15th August (70%), 5th June (62%), and 15th June (56%).
7.2.4. Air layering

In this method, it is possible to get desired-sized plants in a short time but mortality is high and the root system is shallow. Such plants get uprooted in sandy soils due to high wind velocity. Plants develop through air-layering perform better in shallow soils in west-coast. Air layering is done in the rainy season as high humidity facilitates rooting. One to two year old, 45-60 cm long mature branches of pencil thickness with dark green foliage are selected. The bark of 2.5 to 3.0 cm length is removed carefully on which IBA (2000 ppm) + NAA (10,000 ppm) each in lanolin paste is applied and covered with rooting media especially sphagnum mass. Rooting occurs in 2-3 months. Six months old layer plant is ideal for plantation.

7.2.5. Budding

This is a cheaper, easier, and more efficient method. A single bud is employed for budding. This method can be adopted all over the coastal regions of the country where the climate is moist and rainfall is heavy. For budding, May month is the best. In this, a flap of bark is eased out in the form of a tongue and the bud along with a little bark attached to it is inserted underneath the flap and covered, keeping this scion bud exposed. After the union, the bud starts developing and the top of the seedling is cut a little above the bud union.

7.2.6. Top working

Unproductive tree can be converted to productive ones by this method. It is accomplished by cuttings trees back to a 3 feet height (1 meter) stump, whitewashing the entire stump, and then veneer grafting is done on several new shoots when they reach ½ inch (13 mm) in diameter or larger. The best time for grafting of shoots of the beheaded tree is the beginning of the monsoon.

7.3. Micropropagation

A complete protocol for micropropagation of sapota using cotyledonary node segments has been developed by Purohit and Singhavi (1998). Multiple shoots were induced in vitro from nodal segments through forced-axillary branching. Schenk and Hildebrandt’s (SH) medium supplemented with 2.0 mg/L BAP induced up to three shoots per node with an average shoot length of 2.17 cm in 42 days. Further multiplication of shoots required continued culturing up to three passages of 21 days each on the same medium after the establishment of cultures. Thereafter, a 3-fold multiplication rate was achieved during every subculture. Incorporation of GA_3 (1.0 mg/L) in the medium during the first subculture after establishment and initiation of shoot buds not only improved the shoot elongation but also enhanced the rate of shoot multiplication. One time use of GA_3 during the first sub-culture eliminated the need for prolonged culturing on BAP medium. A three-fold rate of shoot multiplication could be achieved after this treatment. Further, use of GA_3 in the medium was not useful.
The shoots could be multiplied for at least 24 months without loss of vigour. Implantation of shoots on half-strength SH medium after a pulse treatment of pre-autoclaved IBA (200 mg/L) for half-an-hour induced rooting in 66% shoots with a moderate degree of callusing. Seventy-seven percent callus-free rooting was obtained when shoots after treatment with pre-autoclaved IBA (200 mg/L) for 2h were directly implanted on autoclaved soilrite contained in culture bottles and irrigated with 1/4 SH solution. This allowed rooting and partial hardening simultaneously. Ninety percent of such plantlets could be transferred to pots. Of 500 plantlets, 440 have been successfully established in the soil.

8. IMPORTANT VARIETIES

There have been several new cultivars developed in the USA, India, Philippines, Mexico, and Venezuela. Varieties with good horticultural characteristics should have a high yield, moderately large to large fruit, and smooth, sweet, and aromatic pulp with little or no grittiness. Thick-skinned, hard-fleshed cultivars with sandy texture are considered inferior. Most of the present-day sapota cultivars are the result of seedling selection and its cultivation is based on a narrow genetic base. The sapota cultivars grown commercially in different states of India have been presented in Table 4 and chief characteristics of some important varieties are discussed hereunder.

International varieties

Alano

It is grown in the United States (Hawaii). The fruit is conical to round, skin light brown, smooth, 115-120g. The pulp is smooth to slightly granular, very good to excellent. Season: November-June.

Betawi

The variety is popular in Indonesia. The fruit is conical, 315 g, pulp light amber – yellow, slightly granular, very good and juicy. Season: late December.

Brown Sugar

It is grown in the United States. The fruit is round to ovate, skin light brown, moderately scurfy, 133-170g, brown, slightly granular. Season: May – September.

Gonzalez

It is grown in the Philippines. The fruit is round to oval, skin very light brown, slightly scurfy, 260 g, the pulp is light brown to brown, smooth, very good to excellent. Season: November – April.
Sapota (*Manilkara achras* (Mill.) Fosberg)

**Hasya**

It is grown in Mexico. The fruit is oval to slightly conical, skin light brown, moderately scurfy, 365 g, the pulp is brownish-red excellent. Season: November – June.

**Makok (dwarf) tree**

It is grown in Thailand. The fruit is conical, skin light brown, slightly scurfy, 140 g, the pulp is light brown to slightly greenish-red, smooth. Season: May – November.

**Modello**

It is grown in the United States. The fruit is elliptic to ovate, skin light brown, moderately scurfy, 30 g, the pulp is whitish to tan, smooth. Season: February – May.

**Indian varieties**

**CO-1**

It is a hybrid developed by crossing Cricket Ball x Oval at Tamil Nadu Agricultural University, Coimbatore. This variety is superior to either of the parents. The fruits are long oval (egg-shaped), medium in size with a mean fruit weight of 125 g. The flesh is granular in texture and reddish-brown in colour, the taste being very sweet with a TSS of 18° brix.

**CO-2**

It is a clonal selection from Baramasi. Fruits are obovate to round, medium-sized, skin outer surface cinnamon-brown in color, inner surface yellowish green, flesh soft, juicy, slightly gritty, light brown in color, aroma slight, taste sweet, seed medium-sized, black, obovate in shape, beaked, suture distinct, slightly adhering to flesh and placed centrally in the fruit. The length, diameter, and weight of fruits range from 4.0 to 6.5 cm, 5.0 to 7.0 cm, and 112-168 g respectively. The number of seeds per fruit varies between two and eight. The mean acidity of the fruit is 0.13 with a reducing sugars content of 12.8 %, non-reducing sugars of 3.94 %, total sugars of 16.95 %, and total soluble solids of 23.10 %. Approximately fruits take six months from fruit set to harvest, with two bearing seasons (December – February, and May-June). The yield is 175 kg/tree or 11.8 tons /ha/year at the rate of 67 trees planted at 40 feet spacing.

**CO-3**

It is a hybrid between Cricket Ball and Vavi Valasa released by TNAU, Coimbatore. The trees are of intermediate stature with a compact canopy. Highly suitable for high-density planting. It bears fruits all through the year with a peak during February-June and September-October. A well-grown tree yields up to 157 kg of fruits as against 109.5 and 101.32 kg/tree by CO-2,
CO-1 respectively. Under a high-density planting system, it yields 40-50 t/ha. It is suitable for growing in plains up to an elevation of 100 MSL under a wide range of soil conditions.

**PKM-1**

A clonal selection from the variety Guthi developed at Horticultural College Periyakulam of Tamil Nadu Agricultural University. The tree is dwarf in stature. Fruits are of two shapes *viz.*, round and oval. The skin is very thin and the pulp has a buttery consistency, very sweet with a TSS of 24° brix. High yielder with medium size fruits, individual fruit weight ranging from 88 to 120 g.

**PKM-2**

It is a hybrid between Guthi and Kirthi Barthi developed at Horticultural College and Research Institute, Periyakulam of Tamil Nadu Agricultural University. A high yielder with a yield performance of 1500 to 2000 fruits per tree per year weighing 80 to 100 kg. Fruits are bigger and oblong to oval-shaped. The average fruit weight is 95 g. TSS ranges from 25 to 27° brix.

**PKM-3**

It is a hybrid between Guthi and Cricket ball. It has a vertical growth habit and hence lends itself for high-density planting. Trees bear big sized fruits with an oval shape and have cluster bearing habit. The fruit yield is 14 tonnes per hectare.

**PKM (Sa) 4**

It is a clonal selection from PKM 1 developed by Horticultural College and Research Institute, Periyakulam, high yielder (100.4 kg/tree/year) 138.29% increase over PKM 1. Fruits are spindle-shaped suitable for dry flakes production. Pulp attractive with light pinkish honey brown colour, crisp and sweet flesh TSS 24 – 25° brix; less seeded (2 – 3 seeds/fruit).

**PKM (Sa) 5**

It is a selection from open-pollinated seedlings maintained at a private orchard at Virudhunagar. Leaves are waxy, narrow, small, upright, and arranged in whorl form in a cluster and rich in proline content, relative water content, epicuticular wax, and chlorophyll stability index. High yielder, High Total Soluble Solids (25.50 brix), and suitable for preparation of dry flakes, milkshake powder, and mixed fruit jam. Suitable for vertisols, water stagnated, and drought areas. Oval shaped attractive fruits with smooth, light brown skin which facilitates a good market appeal. The flesh is crisp and retains coppery brown colour while other sapota varieties turn dark brown after ripening. Since the fruits are heavier with coloured flesh than other varieties, it is highly suitable for making flakes, powder, and mixed fruit jam. It shows
field tolerance to leaf spot and leaf webber incidences. This can be best planted during June – October. This is having a yield potential of 18.70 t/ha which is a 19.06 % yield increase over (PKM 1) and 17.97 % (PKM 4). This is well adapted to the vertisol soils of Southern Tamil Nadu and water stagnated and drought-prone areas.

**DHS 1**

It is a hybrid between Kalipatti and Cricket Ball. The tree is vigorous, bearing round to slightly oblong fruits with high yield. The fruits are very sweet having a soft, granular, and mellowing flesh with a TSS of 26° brix. The colour of the pulp is light orange. The mean fruit weight is 150 g.

**DHS 2**

It is hybrid between Kalipatti and Cricket Ball. High yielder, yielding 25 to 30 % more than cricket ball and kalipatti, with very sweet, soft, granular, and mellowing light orange-brown pulp.

**Pala**

Pala is a popular variety in Andhra Pradesh and Tamil Nadu. The fruits are small to medium-sized and oval or egg-shaped, with apex broadly pointed and are very sweet. The bearing is heavy and fruits are borne in a cluster. The fruit has thin skin and a good flavour.

**Baramasi**

It is a popular variety in West Bengal, Bihar, and Uttar Pradesh. The fruits are medium in size and roundish. It does not, however, bear throughout the year as the name indicates.

**Bhuri or Bhuripatti**

It has thick foliage but the leaves are medium-sized; bearing is medium. Fruits are large and of good quality.

**Chhatri**

It is similar to Kalipatti but the branches have a drooping nature similar to that of an umbrella. The branches appear horizontally in all directions in whorls. The leaves are light green. Fruits are similar to Kalipatti in appearance but the fruit quality is not as good as in Kalipatti. It is a fairly good cropper but not as heavy as Kalipatti. It is also an important cultivar in Maharashtra.

**Cricket Ball**

It is also known as Calcutta Large. The fruits are large and round. The pulp is gritty, granular, and moderately sweet. The variety performs well in both arid and humid climates.
**Dhola Diwani**

This cultivar is grown in Maharashtra. Trees have light green foliage. It bears oval fruits of good quality which are harvested in summers. Fruits are of small-sized with thin skin and are superior in quality. The pulp is sweet. Some hybrids have also been released for cultivation.

**Dwarapudi**

The fruits resemble to those of Cricket Ball but are smaller in size. It is popular in Andhra Pradesh. Fruits have a sweet pulp and are in great demand.

**Jonnavalasa I**

It is a popular cultivar of Andhra Pradesh. It bears medium-sized fruits with rough skin which is thin and without ridges. The pulp is cream-colored and sweet.

**Jonnavalasa II**

It is grown in Andhra Pradesh. Fruits are medium-sized, ovate with a prominent depression near the stalk end. The fruit skin has a buff colour with whitish flakes and eight marked ridges. The flesh colour is like that of musk melon with a golden tinge towards the cavity.

**Jonnavalasa Round**

Fruits are small to medium in size and round in shape. It is a popular cultivar in the Vizianagaram district of Andhra Pradesh. A small cavity is seen at the stalk end and has 10-11 ridges. The pulp is firm, cream-colored, and very sweet.

**Kalipatti**

It is a leading variety of Maharashtra, Gujarat, and North Karnataka. Fruits are oval-shaped, less seeded with a sweet mellow flesh of excellent quality and mild flavor. Fruits appear singly.

**Kirthi Barthi**

The fruits are small to medium-sized and oval-shaped. There are 4-6 ridges on the rind. Fruit skin is rough, medium-thick, and buff coloured. The pulp is sweet. Fruit apex is rounded. The fruits are suitable for long-distance transport.

**Pot Sapota**

Fruits are borne when the plants are still in pots and hence the name. This bears small-sized, oval fruits with pointed apex and no ridge on the surface. The fruit is exceedingly sweet with good flavor.

**Jingar**: Medium-sized tree, small leaves, fruits in clusters
**Vanjeet:** Slow growing, knots on stems shy bearer, superior

**Vavivalasa:** The variety exists in Andhra Pradesh. The fruits are oval, medium-sized, medium quality

**Calcutta Round:** The foliage is high green in color. Fruits are large, with gritty flesh. It is prone to leaf spot disease

**Long:** The variety has narrow and small leaves, fruits are long and it is a poor bearer.

**Table 4: Sapota varieties grown in various regions of India** *(Shirol et al., 2019)*

<table>
<thead>
<tr>
<th>State</th>
<th>Varieties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andhra Pradesh</td>
<td>Cricket Ball, Dwarapudi, Gutti, Jonnavalasa, Kirthabartha, Pala and Singapore</td>
</tr>
<tr>
<td>Gujarat</td>
<td>Bhuripatti, Cricket Ball, Dhola Diwani, Jhumakhia, Kalipatti and Pilipatti</td>
</tr>
<tr>
<td>Karnataka</td>
<td>Cricket Ball, DHS 1, DHS 2, Kalipatti, Kirthabartha and Pala</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>Cricket Ball, Kalipatti and Murabba</td>
</tr>
<tr>
<td>Tamil Nadu</td>
<td>Co-1, Co-2, Gutti, Kirthabharti and Pala, PKM-1</td>
</tr>
<tr>
<td>Telangana</td>
<td>Cricket Ball, Kalipatti, Kirthabhathi and Pala</td>
</tr>
<tr>
<td>Others</td>
<td>Baramasi, Cricket Ball, Oval and Round</td>
</tr>
</tbody>
</table>

9. **ORCHARD ESTABLISHMENT**

A location, free from water stagnation should be selected. The land should be ploughed 2-3 times and leveled. Undulated land should be divided into terraces depending on the topography of the land and leveling should be done accordingly. It is advisable to grow a green manure crop and plough it to improve the soil before planting. It is ideal to plant sapota saplings at the beginning of the rainy season (June- July). However, it is a crop of warm and humid tropical climate; hence it can be planted in any season provided sufficient irrigation facilities are there. In high rainfall areas, it can be planted in September.

In light soils, a pit of 60x60x60 cm³ size whereas, in heavy and gravel soils, pits of 1x1x1 cubic meter are made in April – May. The pits are exposed to solarization for 20-25 days. Topsoil (30 cm) is mixed with an equal quantity of farmyard manure, 3 kg superphosphate 1.5 Kg muriate of potash and 100 g methyl parathion dust (2%) or quinolphos dust (1.5%) is used for filling of pits. Add carbofuran @ 10 g/pit. Pits are filled up to a height of 15 cm above the soil surface. Pits are left to monsoon rains or irrigated manually for settling of soil mixture and then planting is done. At the time of planting, a hole is made in the center
equal to the size of the graft ball. Before plantation, the side of the plantation hole as well as the graft ball surface is dusted with bavistin 50% WP and methyl parathion dust to avoid fungal infection and pest attack.

The graft joint must be at least 15 cm above the ground level. Stake the plants properly to avoid bending or damage to the graft joint. Plantation should be done in evening hours and soil around the plant is gently and firmly pressed to remove air space. The plants are lightly watered and thatched with local grasses on top as well three sides excepting the southeast for proper sunlight penetration. In flat surface lands, a square system of planting is recommended. However, in lands with a 5-15% slope, contour plantation is recommended.

Sapota is normally planted at a wide spacing of 8 m x 8 m and grows very slow and takes 10 – 12 years to occupy the allotted full space depending on the level of management, climate, and edaphic conditions. Results under AICRP revealed that plant density of 8m x 4m (312 plants) per hectare recorded the highest yield (15.35 t/ha) for 15 years old PKM-1 sapota under Periyakulam conditions. At Kovvur, maximum yield (6.56 t/ha) was recorded in 7.5 x 5.0m spacing for seven-year-old Kalipatti trees. To obtain higher fruit yield from per unit area during formative years, planting at 5m x 5m spacing is beneficial up to 13-years (Anon., 2014).

10. HIGH-DENSITY PLANTING

Sapota trees are normally planted at a distance of 8 x 8 m spacing, accommodating 156 trees per hectare. Due to less number of trees under this system, the productivity is low. To increase the productivity of sapota orchards, high-density planting has to be followed for the efficient utilization of land and other natural resources. Identification of dwarfing rootstocks and management strategies may help for HDP in sapota. Patel et al. (2001) reported from the results of six years of study that the yield of sapota cv. Kalipatti had a significant effect on yield under HDP with the highest yield of 13.61 t/ha in 5 x 5 m and the lowest (5.05 t/ha) under 10 x 10 m spacing. The spacing trial conducted at Horticultural College and Research Institute, Periyakulam revealed that a spacing of 8 x 4 m (312 trees/ha) registered the highest estimated yield of 18.00 t/ha in PKM 1 variety.

11. CROP MODELING

Being an evergreen fruit crop with better marketability, sapota acquired minimal attention over the phenology description. Kishore and Mahanti (2016) examined the codes and phenological stages (seven primary growth stages and forty one secondary growth stages) of sapota with extended BBCH (Biologische Bundesantalt, Bundessortenamt und Chemische Industrie) scale using three-digit numerical system. Observations revealed that extended
BBCH scale is broadly applicable for sapota. All the phenophases concern to vegetative and reproductive stages were described in positive way and paved the way for essentiality with crop managerial and improvement criteria. The study found to act as a mean in conserving crop managerial practices viz., nutrient, water and pest, floral and fruit drop management in a fine way. Additionally, it is also supportive in the germplasm characterization and assessment of climate effect over crop phenology.

12. INTERCULTURAL PRACTICES

The long pre-bearing phase, the large statue of the trees, poor fruit set, flower, and fruit shedding are some of the production problems in sapota which can be managed through suitable horticultural techniques as follows:

12.1. Training and pruning

The development of a strong limb framework is important to allow the sapota crop to carry large crops of fruit without limb breakage. If the tree is leggy and lacks lower branches, remove part of the top to induce lateral bud break on the lower trunk. Besides, shoot tip removal (1 to 2 inches) of new shoots of about 3 feet in length, once or twice between spring and summer will force more branching and make the tree more compact. Any limbs that have a narrow crotch angle should be removed because these may break under heavy fruit loads. Most trees are trained in the central leader system. A seedlings tree grows excellently giving a shape of an umbrella. However, plants raised through inarching require training for appropriate shape. In the beginning, the basal branch helps in developing a thick central system, and hence care must be taken to maintain proper distribution of branches on all sides. In sapota, new growth and flowering occur simultaneously and it has a mixed type of bearing habit. Flowers and fruits appear in the leaf axils in the new growth and hence pruning of branches should not be done.

Sapota being an evergreen tree requires no regular pruning but regulation of vegetative growth to improve productivity and quality of fruits is necessary. Dried stems and branches, crowded branches, branches arising in the interior of the canopy, and those criss-cross branches should be pruned in June. Rootstock sprouts should be removed regularly. All the growth that appears on the rootstock below the graft joint must be removed. As trees mature, most of the pruning is done to control tree height and width and to remove damaged or dead wood. Trees should be kept at a maximum of about 3.7 to 4.6 m. Low branches should not be cut, however, unless they touch the soil. Cultural practices eg., picking, spraying, and pruning are easier on small trees. In a pruning trial at Periyakulam, sapota trees were pruned (10m x 5m x 5m canopy) and applied paclobutrazol at 8-12 ml/tree to sustain the fruit productivity (Anon., 2004). Thinning of the tree has been recommended at the age of 13 years in Gujarat (Anon, 2015).
12.2. Irrigation management

Sapota demands a continuous supply of water. Irrigate the sapota plants copiously immediately after planting and need-based irrigation after cessation of monsoon and during summer is essential. Young plants should be irrigated necessarily for one year. Under Karnataka conditions, light soils crop can be irrigated through surface furrow at 8-10 days interval while, in heavy soils once in 25-28 days. For young trees, up to 6 years water can be given through drip @ 11 liters/plant/day in Kharif (June-July), 18 liters/plant/day in rabi (September-October), and 25 liters/plant/day in summer (April-May). In Gujarat, drip irrigation for 150-420 minutes using 2-4 drippers (8 LPH) and placing 1 m away from the trunk plantation is recommended for a 3 to 6-year-old Sapota tree in cv. Kalipatti planted at 10 x 10 m spacing. Adult trees require drip irrigation for 60 minutes in winter and 90 minutes in summer by using 8 drippers of 8 LPH and placed 1-2 m away from the trunk (Anon, 2015).

Under the moisture-stress condition, the plant produces one crop only. Young trees have been observed to defoliate or decline due to lack of water; therefore, young trees should be watered periodically during dry periods. Mature leaves are tolerant of dry soil conditions. However, for optimum fruit production and quality, periodic irrigation during long dry periods is recommended from flowering till harvest.

Sapota is highly tolerant of high salt concentration while in light and well-drained soil, brackish water can also be used to irrigate without any record of injurious effects (Rajashekhara et al., 2013). Typical symptoms of salt stress include marginal and tip necrosis of leaves, leaf browning and drop, stem dieback, and tree death. According to Tiwari et al. (2014), the yield of sapota was observed to be enhanced by 21.05% due to drip in comparison to ring basin irrigation. They also added that the maximum daily water requirement of the sapota plant was estimated at 6.89 mm from 30th April to 6th May (18th week) and minimum as 2.14 mm in the winter season from 17 to 23 December (51st week).

12.3. Weed management

Weeds compete for nutrients and moisture; and harbor pests and diseases; hence these should be removed frequently. For control of grassy weeds, spray of glyphosate @ 5-8ml/ liter is recommended under Andhra Pradesh conditions. In established orchards, pre-monsoon and post-monsoon inter cultivation is recommended for better aeration and effective weed control. Plough the field thoroughly during the onset of monsoon and once later. In young orchards, weed hazard is common. Use of 2 kg bromacil + 2 kg diuron/ha as a pre-emergence spray is also effective for 10-12 months.

12.4. Establishing windbreak

Young plants are likely to damage due to the scorching sun, dry and hot wind, and frost.
A strong windbreak should be established by planting tall and thick growing trees on the windward especially in West and North directions or on all the sides of the orchard.

12.5. Mulching

Bio-mulching using dry leaves, paddy straw, paddy husk, jowar trash, sawdust, dry grasses, dry sugarcane leaves, dry coconut leaves reduce water evaporation losses, check weed growth, and create a micro-climate which regulates soil temperature, humidity and microbial activity. However, all these materials though beneficial were found to have inherent weaknesses and cost disadvantages. This leads to the use of plastic films as mulches which are the most preferred material. Plastic films improve moisture conservation, increase soil temperature and eliminate weed growth, and hence increase crop yield. The soil under the mulch remains loose and friable. Aeration and soil microbial activity is enhanced under mulch strip and results in more vigorous, healthier plants which is more resistant to pest injury.

12.6. Intercropping

Growing of annuals or relatively short duration crops like vegetables or field crops in the inter-spaces during the gestation period of orchard crops is generally referred to as intercropping. Sapota, being a slow grower, it takes longer period to occupy vacant spaces between two plants of recommended spacing. Therefore, legumes like cowpea, cloture bean, lima bean, peas, and short duration vegetable crops may be raised as an intercrop during the pre-bearing stage. Intercropping of banana, papaya, pineapple; French bean, tomato, brinjal, cabbage, cauliflower, and cucurbits are recommended depending on climate and water resources. Frequent weeding or mulching is necessary for the first few years. Keep a separate irrigation system for the fruit plants. Care should be taken that the root system and scaffolds are not damaged during ploughing.

12.7. Nutrient management

For optimum crop productivity in sapota, the plant leaves should have N -1.76 %, P- 0.18 %, K- 0.82 %, Fe- 122.15 ppm, Zn -26.56 ppm, Mn -31.18 ppm, and Cu - 12.87 ppm (Parmar, 2002). For leaf analysis, sampling should be done in September and the 10th leaf from apex having a sample size of 30) should be taken for diagnosis (Annpurna et al., 1988).

Under rainfed conditions, fertilizers should be applied before or at beginning of the monsoon as per moisture availability from the rain. However, under irrigated conditions, it should be applied in 2 splits. The total quantity of organic manure and half of the chemical fertilizers should be applied at the beginning of monsoon and the remaining half in the post-monsoon period (September-October).

At Kovvur, Andhra Pradesh, application of 400g N+160g P$_2$O$_5$ + 450 g K$_2$O along with
100 kg of FYM/plant is recommended whereas, at Gandevi, Gujarat 100% RDF (1000g N: 500g P₂O₅; 500g K₂O/tree/year) in the ratio of 25:100:25, 50:00:50 and 25:00:25 percent during June, August, and October, respectively for cv. Kalipatti has been recommended. Also, FYM @ 100 kg is applied in June. Fertilizers should be applied within the radial distance of 2 m from the trunk and up to the depth of 30 cm and thoroughly mixed in the soil. In Karnataka under Arbhavi conditions, 10 kg vermicompost + 400 g N, 80 g P₂O₅, and 300 g K₂O per plant are recommended. Out of this 10 kg vermicompost + 200 g N, 80 g P₂O₅, and 150 g K₂O given at the beginning of monsoon (Kharif season- June) and remaining 200 g N and 150 g K₂O in September (Rabi season). Application of 50 Kg of FYM, 1.0 Kg N, 1.0 kg P, and 1.5 Kg K annually have been recommended by Periyakulam, Tamil Nadu (Anon, 2015).

In an experiment on 10-year old sapota plants cv. Cricket Ball grown in laterite soil, Ghosh et al. (2012) recorded the highest fruit yield and fruit weight with the application of 400g N, 100 g P₂O₅ and 300g K/plant/year, which were associated with the foliar N/K ratio of 1.8. They also noted that different levels of nitrogen and potassium did not influence fruit quality.

Sapota trees generally do not develop iron deficiency, even when grown in the rocky, calcareous, high pH soils of Miami-Dade County. If iron deficiency symptoms appear (chlorotic leaves with green veins), apply the iron. In Zn and Fe deficiency, the requirement should be met through the application of organic manures and spraying of ZnSO₄ and FeSO₄ (0.5%).

13. FLOWERING, POLLINATION, AND FRUIT SET

13.1. Flowering

Vegetatively propagated plants of sapota start flowering from the second or third year after planting. However, the economic yield is only obtained from the seventh year onwards. Under the tropical climatic conditions, sapota flowers throughout the year with main two flowering seasons i.e. July to November and February - March. Flowers are borne on past seasons’ shoots. The tree flowers continuously in several flushes at short intervals throughout the year. Fruit production increases with age up to 30 years followed by a decline. Fruits mature about 4 months after flowering.

13.2. Pollination and fruit set

It is a wind-pollinated crop. Flowers are protogynous and the stigma grows out of the bud about two days before anthesis. Flowers open between 4-4.30 a.m. Anthers dehisce between 8-10 p.m. The flowers keep fresh for nearly two days. The stigma is receptive for two days before opening and continues up to 12 hours after opening. Peak receptivity is between 8-10 a.m. The total time taken from fruit set to maturity is 10-12 months under North Indian conditions but in Tamil Nadu, it takes only 4-5 months.
13.3. Improvement in fruit set and retention

The fruit setting is very high in sapota but fruit retention is very poor. There is a high fruit drop at the early stages. Sapota is a cross-pollinated and fruit set can be improved by spraying GA$_3$ @ 50 - 100 ppm at full bloom and after fruit set. NAA spray @ 25 – 100 ppm at flowering and repeated after 15 days resulted in better fruit set at Navsari, Gujrat (Rathod and Amin, 1981). NAA was found to be better as compared to GA$_3$. Agrawal et al. (2006) found that the application of CCC @400 ppm at flower bud stage and two sprays of NAA at flowering and pea stage of fruit development significantly increased the number of fruits as well as yield and physical parameters of fruits. Spraying of CCC @ 450 ppm significantly increased the number of fruits as well as yield/tree (Bhujbal et al., 2010).

13.4. Fruit growth, development and maturation

The development of the sapota fruit is characterized by a single sigmoidal pattern (Yahia, and Gutierrez-Orozco, 2011). Three stages can be identified during fruit growth: the first, where cell division and maturation of the embryo occur; second, where growth is greatly reduced; and third, where cell enlargement occurs giving rise to another phase of rapid and maximum growth. This phase occurs between 5 and 7.5 months from the fruit set. Carbohydrates and tannins are the main constituents of sapota fruit. Free sugars are in high concentration in the mature fruit, while starch is almost absent. The immature fruit is hard, with a high concentration of latex and tannins and the latter are responsible for the high astringency of immature fruits. The skin of the fruit has a sandy-brown texture that disappears once fully ripe. The flesh becomes soft and very juicy while the sugar content increases with maturity giving the fruit a sweet flavor that resembles that of a pear. Sugar content greatly increases in particular during the last growth phase when fruit harvested at this stage has a higher quality is soft and has a sweet aroma. The fruit can also be harvested after the first growth stage. Sapota is a climacteric fruit and can be harvested when fruits are still hard. It can take 4–10 months for the fruit to be fully ripen, depending on the variety, climate, and type of soil (Baidya et al., 2020).

14. INSECT PESTS AND THEIR MANAGEMENT

Sapota tree is attacked by more than 25 insect pests (Wagh et al., 2012). Important pests and diseases of sapota are discussed below.

14.1. Bud borer *(Anarsia achrasella* Bradley)

This pest is wide spread in all sapota growing areas. Bud borer is a regularly occurring insect pest on sapota trees in middle Gujarat. The larvae attack the flower buds resulting in a considerable flower dropping. One larva of *A. achrasella* could damage up to 36.9 buds before reaching pupation (Jayanthi et al., 2006). The larvae bore into flower buds and feed
on ovary and petals adversely affecting the sapota fruit production. The pest is in severe form from July to November months. Spray of chlorpyriphos @ 2 ml or monocrotophos @ 2 ml/l of water during August-October has been found effective. Installation of one light trap per two sapota tree has also been recommended. The spray of neem seed kernel extracts @ 5 % also found effective in the management of bud-borer at Periyakulam, Tamil Nadu.

14.2. **Leaf webber (Nephopteryx eugraphella Rogonot)**

The larva makes a web with the young leaves and scraps the green epidermis of the leaf. It feeds on buds, leaves, and young fruits. Pest is active from July to November. Spraying of phosalone 35 EC (0.2%) or carbaryl @ 2.5 g/litre was found very effective. Spraying of chlorpyriphos @ 2 ml/l during August-October found effective under Andhra Pradesh conditions.

14.3. **Mealy bug (Phenacoccus icerjoides)**

Mealy bugs are small, oval with a cottony white waxy covering on their entire body. They stick to the undersurface of leaves and base of fruit stalks. They suck the sap and secrete large quantities of a sugary substance causing a drop of flower fruits. Spraying of dimethoate @ of 2ml/liter can effectively control this pest.

14.4. **Fruit borer (Anarsia achrasella Bradley)**

This pest bores into the seed causing loss of economic value. Pest control measures should be taken when fruits are small and marble stone size. The spray of Lamda- cyhalothrin @ 1 ml/Liter and profenophos @ 1 ml/liter with a gap of 30 days can control this pest. Maintaining field sanitation by removing dead and diseased branches, fallen leaves, twigs, and fruits will prevent the pest.

14.5. **Fruit fly (Virachola Isocrates; Bactrocera dorsalis)**

To control fruit fly, a spray of 1.7 ml dimethoate (35 EC) or carbaryl 4 g/l (50 EC) + 10 g jaggery is recommended at Dharwar. Installing 6 methyl eugenol traps per hectare at a height of four feet placed at equal distance in sapota orchard found effective at Gandevi, Gujarat.

14.6. **Seed borer (Trymalitis margarias Meyrick)**

Spraying of chlorpyriphos @ 2 ml/l or lambda-cyhalothrin @2 ml/l) during October-January can control seed borers.

14.7. **Stem borer**

This is a small beetle. The grub is stout and bores into the bark of the stem making circular
galls and feeds on the living tissues of the inner bark of the hole in a trunk. The borer can be traced by cutting the dead bark along the hollow tunnels with a knife. Plugging the hole with a cotton swab dipped in kerosene or BHC 0.1% and then plastering the hole with mud can significantly control the pest.

14.8. Scale insects

These are green or brown scales, oval-shaped with a slight twist at the front end. The characteristic feature is the presence of an inverted loop on the body. These insects infest along the sides of the midrib and sap. Spraying a suitable insecticide such as malathion or dimethoate @30 ml in 18 liters of water effectively controls this pest. Two to three sprays are necessary.

14.9. Leaf miner

It is a tiny caterpillar and the adult is a grey coloured moth. It mines into the surface of young leaves and makes them curl. Infected leaves show glistening irregular galleries or mines on the leaf surface. The tiny caterpillars are seen inside these galleries. Leaves get distorted, dry up, and fall. One or two sprayings of dimethoate @30 ml in 18 liters of water can render effective control.

15. DISEASES AND THEIR MANAGEMENT

15.1. Leaf spot disease

Leaf spot disease is caused by *Phaeophleospora indica*. The disease is characterized by numerous small circular pinkish or reddish-brown conspicuous spots with whitish center on mature leaves resulting in premature defoliation leading to the barren appearance of branches and finally, fruit production suffers adversely. Spraying of carbendazim 1 g/l (0.1%) or copper oxychloride @ 3 g/liter of water from August month onwards is effective against the disease. The tolerant variety of brown leaf spots is PKM-1.

15.2. Sooty mould (*Capnodium sp.*)

Boil 1 kg maida (flour) or starch with 5 liters of water, cool and dilute to 20 liters of water (5%) and spray. Avoid spraying during cloudy weather.

15.3. Fruit drop of sapota caused by *Phytophthora sp.*

In the recent past, there was an increased incidence of fruit drop disease during the rainy season throughout the coastal belt of Maharashtra. Joshi and Kadam (2014) observed that the disease severity during 31 to 35th meteorological weeks (30th July to 2nd September) was
more than 50%. This indicated that the fruiting season of sapota in the rainy season under coastal Maharashtra conditions needs an effective plant protection cover. Four sprays of copper oxychloride (0.25%) at fortnightly intervals have been recommended for control of fruit drop of sapota caused by *Phytophthora sp.*

**15.4. Flat limb**

This disease is caused by *Botryodiplodia theobromae*. The leaves become thin, small, and yellow and there is the clustering of leaves and flowers at the top of affected twigs. Flowers remain infertile and fail to set fruits and even if fruits are set they remain small, hard, and unripe. The affected branch is @ 3 g/L or mancozeb @ 205 g/L is recommended to control the disease.

**15.5. Wilt or dieback**

Wilt is common where sapota cultivation is being extended to traditionally rice-growing regions. Due to anaerobic conditions in monsoon and post-monsoon season in such areas wilt is of common appearance aggravated by *Fusarium* spp. This can be controlled by an effective drainage facility before planting.

**15.6. Postharvest diseases**

Because of the high moisture and nutrient content of the fruit, sapota is especially prone to postharvest diseases. Common diseases include sour rot (*Geotrichum candidum*), cladosporium rot (*Cladosporium oxysporium*), and blue mold rot (*Penicillium italicum*). Benlate is a commonly used fungicide for postharvest treatment of sapota, best to control both fungal and bacterial pathogens of sapota. Although several non-chemical treatments have been tested, none have proven to be successful against postharvest pathogens of sapota.

**16. PHYSIOLOGICAL DISORDERS AND THEIR MANAGEMENT**

**16.1. 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 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 (Yahia and Gutierrez-Orozco 2011). The development of CI symptoms can occur when the 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). Little research on these options has been conducted on sapota. Yahia (2004) reported that different edible
coatings applied after harvests, such as ‘Semperfresh™’ and ‘Sta-fresh™’, maintained fruit quality for 40 days at 10°C without showing CI symptoms. Besides, 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-methyl cyclopropane (1-MCP) (Moo-Huchin et al. 2013).

16.2. 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. Ascorbic acid is 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 methylcellulose 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).

16.3. Misshapen fruits

In general, fruits are oval to round in shape. The shape of the fruit is related to the number of seeds in it which depend on conditions for pollination at anthesis. High temperature and rainfall during flowering result in the development of oblongated fruits. Therefore, the cultivation of sapota in areas with extreme summer temperatures should be avoided. Sometimes fruits do not develop into their normal shape but develop depression or furrow towards the calyx end. This symptom usually appears immediately after heavy rainfall and is aggravated by the high intensity of irrigation. Therefore, over-irrigation should be avoided. The fruits exposed to intense sunlight do not ripen uniformly, developing corkiness during winter, probably due to the killing of hydrolyzing enzymes by alternating moisture accumulation and heating of fruit surface in winter (Radha and Mathew, 2007).

17. MATURITY, HARVESTING, AND YIELD

17.1. Maturity indices

Sapota is a climacteric fruit. Hence, fruit should be harvested at full maturity. It is a little difficult to judge proper fruit maturity due to the overlapping of flowering and fruiting. If
immature fruits are harvested, these take a long time to ripen and quality is always poor. Immature fruit may not soften for many days, may not develop optimum sweetness and flavor, and may contain pockets of coagulated latex within the flesh. It takes about 10 months to mature Sapota fruit. Radha (2014) reported that the fruits in general mature about 240-270 days after flowering. The mature fruits shed off the brown scaly scurf from the skin and development of yellowish tinge intermixed with corky-brown colour on the surface of the fruit. Mature fruit is dull brown (potato colour) and the colour immediately below the skin when scratched is of a lighter shade, while in the immature fruits it is green. If the time of fruit maturity is unknown, we may wait until some fruit drop and then begin to harvest those of similar size.

17.2. Harvesting procedure

It should be harvested along with stalk intact, individually by giving a twist and collected without bruising and kept to the ground carefully. The fruits are also harvested with a special harvester which has a round ring with a net bag fixed on a long pole. Fruits are transported in plastic crates to avoid damage or bruising. They are packed in a bamboo basket with a straw cushion having a 16 Kg capacity. Corrugated trays are equally effective as packaging material while transporting the fruits. The harvested fruits are graded according to size and stage of maturity and washed in water. The use of such trays is cost-effective due to its reusability. Later they are again washed in water containing 500 ppm carbendazim, shade dried, and packed in 20.5 cm x 20.5 cm x 5.5 cm boxes for distant transport. Well matured fruits ripen within 3-5 days after harvest and can be stored for 10-12 days at 12°C temperature. After ripping fruits become very soft and cannot be kept for long. Ripe fruits can be stored at 2-3°C with 85-90% RH for a month.

Cricket Ball is an attractive large-round fruited variety crisp or gritty pulp with moderate sweetness and flavor. However, the fruit quality of October-November flowering (Hast bahar), which matures during August-September is somewhat poor as against July-August (Mrig Bahar) flowering that matures in the month of April-May (Agrawal et al., 2006). The harvesting time of sapota in different states has been presented in Table 5.

Table 5: The harvesting season of sapota fruits in different states of India

<table>
<thead>
<tr>
<th>State</th>
<th>Harvest time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andhra Pradesh</td>
<td>February-March; October-November</td>
</tr>
<tr>
<td>Bihar</td>
<td>February-March</td>
</tr>
<tr>
<td>Chattisgarh</td>
<td>March-April</td>
</tr>
<tr>
<td>Gujarat</td>
<td>January-March; November-December</td>
</tr>
<tr>
<td>State</td>
<td>Season</td>
</tr>
<tr>
<td>----------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Haryana</td>
<td>May-June</td>
</tr>
<tr>
<td>Himachal Pradesh</td>
<td>July-August</td>
</tr>
<tr>
<td>Karnataka</td>
<td>April-November</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>February-March</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>Year round</td>
</tr>
<tr>
<td>Odisha</td>
<td>March-June</td>
</tr>
<tr>
<td>Rajasthan</td>
<td>July-August</td>
</tr>
<tr>
<td>Sikkim</td>
<td>May-July</td>
</tr>
<tr>
<td>Tamil Nadu</td>
<td>April and September</td>
</tr>
<tr>
<td>West Bengal</td>
<td>March-June</td>
</tr>
</tbody>
</table>

Source: Indian Horticulture Database 2019 of National Horticulture Board, Ministry of Agriculture, Govt. of India.

17.3. Yield

The fruiting starts from the third year after planting but the economic yield can be obtained from the seventh year onwards. The yield depends upon several factors, such as the age of the tree, cultivars, location, etc. On average a 10-year-old tree yields about 1000-1500 fruits while a 25-year-old tree can provide 2000-2500 fruits. Ghosh et al. (2014) observed yield patterns of sapota cultivars at different ages in the laterite zone of West Bengal and concluded that economic yield was started from the 8th year of plant age.

18. POSTHARVEST MANAGEMENT AND STORAGE

Fruits ripen in about 3-5 days after harvest at room temperature and the ripening period depends upon the cultivar, stage of maturity, and temperature. Fruits are spread on mats or floor in a single layer. For early and uniform ripening exposing fruits to aqueous solution of ethrel @ 1,000 ppm for 5 minutes is recommended (Madhavi et al. 2005). Sapota fruits were found to be climacteric with the respiratory peak occurring at the same time or 1–2 days after peak ethylene production. The fruits are highly perishable and they undergo rapid ripening changes within 5-7 days during which the fruits become soft, sweet, and develop excellent aroma with a decline in tannins, latex sapotin, aldehydes, and acidity. The changes are associated with an increase in the production of ethylene, the rate of respiration, catalase, peroxidase, and PME activities. These changes can be regulated through chemicals, temperature, and storage gas composition. Harvested fruits should be cleaned of latex and scurf by washing in clean water to make them look attractive.
Shelf life can be extended by dipping in the GA 300ppm + bavistin 1000ppm solution at the pre-packing stage. Mature but unripe fruits should be kept at room temperature for 3 to 5 days to ripen. The firm, ripe sapota can be kept well inside the home refrigerator for up to six weeks at 35°F. Recommended storage conditions are about 20°C with 5–10% CO₂ coupled with the complete removal of C₂H₄ from the storage atmosphere. The short-term holding of the fruit at lower temperatures is also possible. While fruits stored at 5°C sustained chilling injury manifested as uneven ripening, pitting, and hardened pulp. 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 control (ambient condition).

Ghosh *et al.* (2014) made a detailed study about the shelf life of sapota fruits of different cultivars under normal room temperature and concluded that the shelf life of sapota fruits may be considered as 9th day. At Gandevi, NAU Gujarat, sapota fruits are dipped in calcium hydroxide (1%) for 5 minutes and wet rubbed or wiped after drying for improving fruit appearance, then dipped in 2,4-D (4 ppm) or GA3 (300 ppm) or kinetin (100 ppm) extending self-life for 15 days due to reduction of catalase and pectin methylesterase activity, and reductions in respiratory activity and ethylene production. The application of these compounds appears to reduce the rate at which fruit ripens as well as affecting fruit quality characteristics such as total sugars, acidity, ascorbic acid, and starch.

When sapota fruits are pre-cooled at 5-10°C for 8 hours, packed in a perforated polyethylene bag (50 microns) and kept in CFB box then stored at 12°C in cold storage can extend the shelf life up to 15 days (Anon, 2015). Gibberellic acid extends shelf life in sapota when applied @ 150 ppm concentration (Pandey, 2004).

Various chemicals have been used to hasten or delay ripening, to reduce losses, and to improve and maintain color and quality by slowing down the metabolic activities of fruit which ultimately leads to increased shelf life and maintain the marketability of the fruit for a longer period. CaCl₂ (5000 and 10000 mg/l) was proved very effective in reducing loss in weight, spoilage, and registered high fruit firmness, increase shelf life, and ripening period. Gibberellic acid (GA₃) (150 and 300 mg/l) was also effective in enhancing storage period up to 12 days (Tsomu and Patel, 2014). According to Padmaja *et al.* (2015), the dip treatment of Aloe vera gel coating 1:2, 7 minutes had best retained the physicochemical characteristics than the other treatments performed and was found to be the most effective treatment in maintaining the fruit quality attributes along with the shelf life extension of about 20 days.

### 18.1. Modified atmosphere packaging (MAP)

Packaging in polyethylene film enhances the shelf life of sapota fruits. Polyethylene bags with 0.4 % perforation and thickness of 100 gauges have been reported effective in decreasing spoilage and delaying the ripening of fruits. Non-ventilated bags lead to excessive
accumulation of moisture causing enhanced fungal growth and spoilage. Sapota fruits can be successfully stored using MAP up to 4 weeks at 10°C and 3 weeks at 15°C, a week longer than those fruits stored without MAP. The chilling injury was observed in control fruits but not in modified atmosphere packaged fruits. According to Kumar et al. (2019), the sapota fruits packed in zeolite-LDPE composite bags synergized with antimicrobial compounds could maintain postharvest quality and increase the shelf-life of sapota fruits.

19. UTILIZATION

Sapota fruits are used for making jams, jellies, osmo-dehydrated slices, and squash. Mature fruits are used in jams and provide a source of raw material for the manufacture of industrial glucose, pectin, and natural fruit jellies. Ripe sapota is eaten as a dessert fruit and also is canned. Products like sweet chutney, dried sapota pieces, sapota milkshake, nectar, blended sapota drinks, pickles, preserves, and candy can also be prepared with good sensory quality. Commercially acceptable wine can also be prepared from clarified juice of half-ripe, ripe, and overripe fruits of sapota (Pawar et al., 2011). Sapota fruits contain high sugars (12-18%), with high flesh to seed ratio (80.9), and serve as the best raw material for the wine industry. The wine industry can also be run throughout the year, as the fruits are available in all the season.

Gunjyal (2005) processed and evaluated sapota powder for use in traditional Indian recopies. The powder was incorporated at 20% by weight into five Indian recopies. Sapota’s natural colour, aroma, and flavor were retained. The best overall results were obtained in coconut burfee, banana milkshake, and banana shikarani. Sapota pulp is used for making sweets and halwa. It is also an ingredient in fruit salads and milkshakes. The milky latex secreted by unripe sapota fruits, known as a chuckle, forms the base for making chicklet and chewing gum. The fruits having firm texture are suitable for its candy preparation.

20. TRADE, AND MARKETING

Fruits are available in the market throughout the year. Most of the fruits are consumed within the country. Export constituted only a very minor fraction of production, 0.08% in 2013-14. Low volume export of sapota is due to non-ideal post-harvest practices, transport procedures, lack of proper storage facilities, outdated handling practices. The export of sapota fruits from India during 2013-14 is given in Table 6. Maximum fruits are exported to the United Arab Emirates followed by Bahrain, Canada, and Oman. In Maharashtra, fruits of Cricket Ball and Kalipatt are exported to the Middle East, UK, Singapore, and Australia. Export specifications developed by the Maharashtra State Agriculture Marketing Board are given in Table 7.
Table 6: Export of sapota from India (Country-wise Qty in MT Value in Rs. Lacs)

<table>
<thead>
<tr>
<th>Country</th>
<th>Quantity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>UAE</td>
<td>823</td>
<td>425</td>
</tr>
<tr>
<td>Bahrain</td>
<td>268</td>
<td>145</td>
</tr>
<tr>
<td>Oman</td>
<td>121</td>
<td>74</td>
</tr>
<tr>
<td>Qatar</td>
<td>99</td>
<td>62</td>
</tr>
<tr>
<td>Canada</td>
<td>77</td>
<td>48</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>70</td>
<td>48</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>58</td>
<td>38</td>
</tr>
<tr>
<td>Singapore</td>
<td>28</td>
<td>20</td>
</tr>
<tr>
<td>Kuwait</td>
<td>38</td>
<td>19</td>
</tr>
<tr>
<td>United States</td>
<td>7.0</td>
<td>9</td>
</tr>
<tr>
<td>Others</td>
<td>17.2</td>
<td>11</td>
</tr>
<tr>
<td>Total</td>
<td>1602</td>
<td>890</td>
</tr>
</tbody>
</table>

Source: APEDA, 2018

Table 7: Export specifications

<table>
<thead>
<tr>
<th>Variety</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Packing</td>
</tr>
<tr>
<td>Cricket Ball &amp; Kalipatti</td>
<td>3 Kg</td>
</tr>
</tbody>
</table>

Source: Maharashtra State Agriculture Marketing Board

21. ECONOMICS OF CULTIVATION

Amutha (2014) worked out the analysis of per acre sapota cultivation in the Vilathikulam block of district Tuticorin, Tamil Nadu. The results revealed that the total cost of sapota production was Rs. 9257.10 per acre. The direct cost accounted for 70.14 percent of the total cost of production. The indirect costs accounted for 29.89 percent of the total cost of production. Among the components of indirect costs, interest on fixed capital formed the major items. It accounted for Rs.1327. The other components of indirect cost included the annual share of establishment cost, depreciation, and interest on working capital and they accounted for 3.44 percent, 4.49 percent, and 7.59 percent respectively. Thus, she concluded that investment in the sapota orchard was economically feasible and financially viable in the Vilathikulam block of district Tuticorin (Tamil Nadu).
22. FUTURE RESEARCH THRUST

» Good table sapota should have a few seeds with melting, sweet pulp. Thick-skinned, hard fleshed cultivar with sandy texture are considered inferior, therefore, extensive survey, collection, evaluation should be carried out for a selection of promising, good quality, high bearing sapota types. Besides, a varietal base suited for export quality to be expanded.

» In northern parts of India, young plants undergo injury during winter months by frost. This is the reason for restricting the sapota growing to sheltered pockets of the northern parts of India particularly in Punjab, Haryana, and Utter Pradesh. Hence, frost resistant cultivars should be screened out for these areas to harvest better fruit quality and productivity.

» Location-specific fruit production technologies are to be developed.

» Canopy management under high-density orchards and rejuvenation technology should also be developed.

» A fertigation schedule is to be developed for sapota.

» Organic sapota production technology should be accessed.

» Effective management of sapota bud borer, seed borer should be worked out along with the identification of their natural enemies and to find out the bio-efficacy of new insecticides.

» Production of sapota through integrated nutrient management should be worked out.

» Development of IPM strategy for controlling major pests and diseases.

» Crop regulation by using hormones and plant growth regulators may be explored.

REFERENCES


