22

Tamarind (*Tamarindus indica* L.)

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**Abstract:** *Tamarindus indica* L., commonly known as tamarind, is a multipurpose long-lived tree best known for its fruit. It is indigenous to tropical Africa and exotic to Asia and Central America. India and Thailand are the major tamarind world producers, generating 300,000 and 140,000 tons annually, respectively. There are two main types of tamarind: sour (the most common) and sweet (mostly comes from Thailand). Tamarind can be eaten fresh (ripe or unripe) and it can be consumed processed into different products. In addition to the use of tamarind fruit in food it has many uses in the pharmacological industry and folk medicine. The ripe tamarind pods are susceptible to different pest and diseases, especially when grown in a big plantation. This chapter will describe the nutritional importance and the postharvest handling of tamarind.

**Key words:** *Tamarindus indica*, postharvest, handling, nutrition, storage, processing.

22.1 Introduction

22.1.1 Origin, botany, morphology and structure

*Tamarindus indica* L. (syns. *T. occidentalis* Gaertn, *T. officinalis* Hook, *T. umbrosa* Salisb) belongs to the family leguminaceae (syns. Fabaceae) and subfamily Caesalpinaceae. The genus *Tamarindus* is monotypic, i.e. it contains a single species. Commonly, *Tamarindus indica* is known as tamarind (the trade and English name). In Spanish and Portuguese, it is called tamarindo; in French, tamarinier, tamarinde; in Dutch and German, tamarinde; in Italian, tamarindizio; in Hindi, it is known as tamarind, tamruhindii and it has other local names as well (e.g. ambli, imli, chinch, etc.). In the eighteenth century, Linnaeus gave it the name *Tamarindus indica*, inspired by the Arabic name tamar-ul-Hind, meaning date of India.

Tamarind is widespread throughout the tropics and subtropics and grows in more than 50 countries in Africa, Asia and Central America. It most probably
originated in tropical Africa (Coates-Palgrave, 1988), although there is a common belief that tamarind is native to India (Morton, 1987) where it is believed to have been introduced thousands of years ago (Hort, 1916), and to have reached Central America in the seventeenth century with the Spanish and Portuguese (Patino, 1969). According to Salim et al. (1998) in Africa tamarind is native to Burkina Faso, the Central African Republic, Chad, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Kenya, Madagascar, Mali, Mozambique, Niger, Nigeria, Senegal, Sudan, Tanzania, Uganda and Zimbabwe and exotic to Mauritania, Togo, Cote d’Ivoire, Egypt, Libya, Ghana, Zambia and Liberia. Also, tamarind is exotic to Australia, Asia (Afghanistan, China, Bangladesh, India, Indonesia, Iran, Laos, Malaysia, Nepal, Pakistan, Philippines, Myanmar, Sri Lanka, Thailand, Papua New Guinea, Cambodia, Vietnam and Brunei) and the Americas (Brazil, Colombia, Cuba, Dominican Republic, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Puerto Rico and southern United States of America). It is widely used in Mexico (see Plate XXXVIII in the colour section between pages 238 and 239), especially in the preparation of drinks (tamarind water, tamarind juices) and desserts.

Tamarind is an evergreen or semi-evergreen bushy tree that has a dense foliage crown. It is a slow growing tree; the annual growth rate of seedlings is about 60 cm and the juvenile stage takes between four and five years, but trees can reach up to 200 years of age. The tamarind tree can reach a maximum height of up to 20–30 m, with bole 1–2 m and trunk diameter 1.5–2 m (Jambulingam and Fernandes, 1986; Stross, 1995). Leaves are bright green in color, alternate and compound with 10–18 pairs of leaflets (see Plate XXXIXA in the colour section). Leaflets are 1.2–3.2 x 0.3–1.1 cm in size, petiolate, and rounded at the apex. Flowers are bisexual, 2.5 cm wide, five-petalled, borne in small racemes, and yellow with orange or red streaks. Buds are pink with 4 sepals and 5 petals. The fruit is a curved or straight pod with rounded ends, 12 to 15 cm in length, covered with a hard brown exterior shell. Fruit pulp is brown or reddish-brown when mature and the fruit pod contains between 1 and 12 flat and glossy brown seeds. Tamarind pulp, seeds and shell are about 55%, 34%, and 11%, respectively, of the tamarind fruit (Rao and Srivastava, 1974). The seed is made up of the seed coat or testa (20–30%) and the kernel or endosperm (70–80%). The shell is light greenish or scruffy brown in color (see Plate XXXIXB in the colour section). The shell is scaly and irregularly constricted between seeds; it is also brittle and easily broken when pressed. The pulp is soft and thick (Coronel, 1991; Purseglove, 1987). The seeds are 1.6 cm long, very hard, shiny, smooth and reddish or purplish brown in color with irregular shape and are joined to each other with tough fibers (Purseglove, 1987). Tamarind pods usually contain 1–12 seeds but the Indian pods contain 6–12 seeds, and are usually longer than the African and South American pods. There are two main types of tamarind: sour (the most common) and sweet (which mostly comes from Thailand). The tamarind tree has the capability to withstand long periods of drought because of its deep tap rooting and extensive lateral rooting system, and also the ability to grow in poor soils because of their nitrogen fixing property (Felker, 1981; Felker and Clark, 1980).
22.1.2 Worldwide importance and economic value

Tamarind is economically valuable and multi-purpose insofar as almost every part of the tree has a use, but the tree is best known for its fruit and the marketability of tamarind fruit has increased consistently over the years. The tamarind major production area is in Asia, where India is considered the major producer with a production of 300 thousand tons annually (El-Siddig et al., 2006) (Tables 22.1 and 22.2). According to the spices board of India, the production area was 58,624 ha in 2006–2007 and the export was 10,200 tons. The potential for Indian export in the past 5 years shows a good market for tamarind, especially in the Gulf Countries and Europe (Kumar and Bhattacharya, 2008). Thailand is the second major producer of tamarind, with 140 thousand tons produced in 1995 (Yaacob and Subhadrabandhu, 1995), and the export amounted to about 7,000 tons in 1999. Sri Lanka exported 6,903 tons of tamarind in 1997. Other Asian countries produce and export tamarind but on a much smaller scale compared to India and Thailand. In the Americas, Costa Rica produces about 220 tons of tamarind annually and is considered quite a large producer. The annual production of tamarind amounts to 37 tons in Mexico and 23 tons in Puerto Rico (Bueso, 1980). The Asian tamarind is mainly exported to Asian countries, Europe and North America, while the

Table 22.1 Area (hectares), production and export (tons) and values (Rs. millions) of tamarind from India

<table>
<thead>
<tr>
<th>Year</th>
<th>Area</th>
<th>Production</th>
<th>Export</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002–03</td>
<td>61,958</td>
<td>178,974</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>2003–04</td>
<td>60,629</td>
<td>183,871</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>2004–05</td>
<td>61,624</td>
<td>194,032</td>
<td>5,944</td>
<td>1,833.98</td>
</tr>
<tr>
<td>2005–06</td>
<td>61,084</td>
<td>192,186</td>
<td>14,101</td>
<td>3,078.20</td>
</tr>
<tr>
<td>2006–07</td>
<td>58,624</td>
<td>190,073</td>
<td>10,200</td>
<td>3,000.00</td>
</tr>
<tr>
<td>2007–08</td>
<td>–</td>
<td>–</td>
<td>11,250</td>
<td>3,100.00</td>
</tr>
<tr>
<td>2008–09</td>
<td>–</td>
<td>–</td>
<td>11,500</td>
<td>4,105.00</td>
</tr>
</tbody>
</table>

Source: Spices Board India, Ministry of Commerce and Industry, Gov. of India. http://www.indianspices.com/

Table 22.2 Quantities (tons) and values (RS. millions) of different commodities of tamarind exported from India

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Quantity 2000–01</th>
<th>Quantity 2001–02</th>
<th>Value 2000–01</th>
<th>Value 2001–02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dried</td>
<td>7071.14</td>
<td>4594.58</td>
<td>151.782</td>
<td>109.667</td>
</tr>
<tr>
<td>Fresh</td>
<td>2278.59</td>
<td>1434.15</td>
<td>33.932</td>
<td>23.988</td>
</tr>
<tr>
<td>Flour meal</td>
<td>572.08</td>
<td>817.97</td>
<td>11.348</td>
<td>15.528</td>
</tr>
<tr>
<td>Seeds</td>
<td>2997.39</td>
<td>887.38</td>
<td>47.131</td>
<td>19.322</td>
</tr>
</tbody>
</table>

Source: Spices Board India, Ministry of Commerce and Industry, Gov. of India. http://www.indianspices.com/
American tamarind is mainly exported to North America and Europe. In most of the producing countries, tamarind does not grow on a commercial scale, and fruits are collected from the wild and home gardens. Although widespread in Africa, no African country cultivates tamarind on a commercial scale and almost all of the produce is consumed locally. Similarly, most of the tamarind produced in India and Thailand is also consumed locally. The sour tamarind is the most widespread; it comprises 95% of the total world production. Thailand is the largest producer of sweet tamarind, being 30% of its crop.

22.1.3 Culinary uses, nutritional value and health benefits
Tamarind fruit pulp has many uses in domestic and industrial food and medicine and is considered the most valuable part of the tree. In most tamarind-producing countries, rural households dry tamarind pods in the sun, separate pulp from the fibers, seeds and shells, and compress and pack pulp in palm leaf mats, baskets, corn husks, jute bags, earthenware pots or plastic bags. The fruit pulp is a common ingredient in curries, sauces, and certain beverages. Ripe tamarind pulp, especially the sweet tamarind, is often eaten fresh. Both sour and sweet ripe tamarind pulps are also consumed processed in desserts, pickles, jams, candy, juice, porridge and drinks. Tamarind, especially the unripe pulp, is used as a spice and sauce in many Asian cuisines. In India a pickle made from tamarind pulp is used as seasoning to prepare fish. Also, unripe fruit dipped in salt or wood ash is eaten as a snack. Tamarind juice is very popular in many countries; a refreshing drink is prepared from the pulp water extract mixed with wood ash or sugar. In Eastern Africa, porridge is prepared from pulp juice cooked with sorghum or maize. Sometimes the pulp juice is fermented into an alcoholic beverage. In Burkina Faso, tamarind pulp extract is used to purify drinking water (Bleach et al., 1991).

In many Asian countries tamarind balls are made from the pulp mixed with sugar. In Thailand, the pulp is mixed with salt, compressed and packed in plastic bags. In East India, the pulp is covered with salt, rolled into balls, exposed to dew and stored in earthenware jars (Chapman, 1984; Morton, 1987), whereas in Java, the salted pulp is rolled into balls, steamed and sun-dried, then exposed to dew for a week before packing in stone jars. In Sri Lanka, the dried pulp is mixed with salt, packed in clay pots and kept in a dry place; seedless pulp is stored in plastic bags in retail shops (Gunasena, 1997).

Tamarind seeds are eaten, roasted or boiled, during off-seasons and food shortages. Roasting the seeds is usually followed by decorticating the testa from the edible kernel. Roasted tamarind seeds can also be used as a substitute for coffee. The seed oil is edible and has many culinary uses. Of the tamarind seed kernel, 46 to 48% consists of a gel-forming substance, known as jellose or polyose, which has many applications in the food industry. Jellose is mainly a polysaccharide and can be used for the preservation, thickening, stabilizing and gelling of food (Gliksman, 1986; Chen et al., 1988; Kawaguchi et al., 1989). Unlike fruit pectin, tamarind seed polysaccharide is characterized by its ability to form gels over a
wide range of pHs and gelatinizes with sugar concentrates in cold neutral aqueous solutions (Savur, 1948). Also, tamarind polysaccharides are heat resistant and are not affected by long boiling periods, while fruit pectin degrades to one-third of its original value after one hour of boiling. Tamarind kernel powder (TKP) is a more effective gelling agent when combined with other gums (Yin and Lewis, 1981). Protein concentrates have also been made from tamarind kernel powder (Rao and Subramanian, 1984) and can be used to prepare jelly, and fortified bread and biscuits (Bhattacharya, 1990; Bhattacharya et al., 1994). The shelf life of fish can be extended by using TKP as a film forming gum (Shetty et al., 1996).

Tamarind fruit pulp is a good source of minerals and a rich source of riboflavin, thiamin, and niacin, but it is poor in vitamins A and C (Table 22.3). Shankaracharya (1998) found that the whole tamarind seed contains 13% crude protein, 6.7% crude fiber, 4.8% crude fat and 5.62% tannins. Also, the seed contains good phytic acid, pentose, mannose, and glucose as principal soluble sugars (Ishola et al., 1990) as well as valuable amino acids (Shankaracharya, 1998; Bhattacharya et al., 1994). Bhattacharya et al. (1994) showed that tamarind seed is rich in glutamic acid, aspartic acid, glycine, and leucine, but deficient in sulphur-containing amino acids. The edible seed kernel was reported to be rich in phosphorus, potassium, and magnesium, but has a calcium content comparable with other cultivated

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Amount per 100 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>115–216 calories</td>
</tr>
<tr>
<td>Moisture</td>
<td>28.2–52 g</td>
</tr>
<tr>
<td>Protein</td>
<td>2.40–3.10 g</td>
</tr>
<tr>
<td>Fat</td>
<td>0.1 g</td>
</tr>
<tr>
<td>Fiber</td>
<td>5.6 g</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>51.5–67.4 g</td>
</tr>
<tr>
<td>Invert sugars</td>
<td>30–41 g</td>
</tr>
<tr>
<td>(70% glucose; 30% fructose)</td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>2.9–3.3 g</td>
</tr>
<tr>
<td>Calcium</td>
<td>35–170 mg</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>54–160 mg</td>
</tr>
<tr>
<td>Iron</td>
<td>1.3–10.9 mg</td>
</tr>
<tr>
<td>Sodium</td>
<td>24 mg</td>
</tr>
<tr>
<td>Potassium</td>
<td>116–375 mg</td>
</tr>
<tr>
<td>Vitamin A</td>
<td>15 I.U.</td>
</tr>
<tr>
<td>Thiamine</td>
<td>0.16 mg</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>0.07 mg</td>
</tr>
<tr>
<td>Niacin</td>
<td>0.6–0.7 mg</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>0.7–3.0 mg</td>
</tr>
<tr>
<td>Tartaric acid</td>
<td>8–23.8 mg</td>
</tr>
</tbody>
</table>

Data derived from: Morton (1987); Khairunnur et al. (2009); Khanzada et al. (2008)
Table 22.4  Mineral content of tamarind pulp, seed, kernel, and testa

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Pulp</th>
<th>Seed</th>
<th>Kernel</th>
<th>Testa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>81.0–466.0</td>
<td>9.3–786.0</td>
<td>1200.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>86.0–190.0</td>
<td>68.4–165.0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Magnesium</td>
<td>72.0</td>
<td>17.5–118.3</td>
<td>180.0</td>
<td>120.0</td>
</tr>
<tr>
<td>Potassium</td>
<td>62.0–570.0</td>
<td>272.8–610.0</td>
<td>1020.0</td>
<td>240.0</td>
</tr>
<tr>
<td>Sodium</td>
<td>3.0–76.7</td>
<td>19.2–28.8</td>
<td>210.0</td>
<td>240.0</td>
</tr>
<tr>
<td>Copper</td>
<td>21.8</td>
<td>1.6–19.0</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Iron</td>
<td>1.3–10.9</td>
<td>6.5</td>
<td>80.0</td>
<td>80.0</td>
</tr>
<tr>
<td>Zinc</td>
<td>1.1</td>
<td>2.8</td>
<td>100.0</td>
<td>120.0</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.5</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Manganese</td>
<td>–</td>
<td>0.90</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Data derived and adapted from: Gunasena and Hughes (2000), Khanzada et al. (2008); Khairunnur et al. (2009)

Tamarind fruits are known for their medicinal properties and have been used as herbal medicine in tamarind-producing countries (Jayaweera, 1981). Tamarind pulp is used to treat conditions such as intestinal ailments and skin infections which the pulp juice is used as a gargle to treat sore throats. Tamarind pulp also has uses as an anti-inflammatory (Rimbau et al., 1999) and has anti-bacterial, anti-fungal and molluscicidal properties as well (Imbabi et al., 1992). Tamarind pulp extract is used to cure malaria fever, alleviate sunstroke and as a digestive agent, and in the pharmaceutical industry, tamarind pulp is a common ingredient in cardiac and blood sugar reducing medicines.

Tamarind seeds are considered a famine food, rich in protein. After removing the testa, which contains tannin and other anti-nutritional factors, they are consumed to prevent undesirable effects such as depression, constipation, and diarrhea (Rao and Srivastava, 1974; Khairunnur et al., 2009). The seed was reported to have anti-diabetic effects (Rama Rao, 1975; Maiti et al., 2004) and to treat dysentery, ulcers and bladder stones (Rama Rao, 1975). Seeds have also shown anti-oxidant activity (Osawa et al., 1994; Luengthanaphol et al., 2004; Khairunnur et al., 2009). Shimohiro (1995) reported that the quality of food was improved by adding the polysaccharide hydroxylates or xyloglucan oligosaccharides of tamarind seeds, which are known to have hypolipidemic effects. The tamarind seed coat was reported to be rich in procyanidin, which is known to have an anti-obesity effect (Koichi et al., 1997; Osumu et al., 1997), while a reduced-calorie food can be prepared using the cellulase hydrolysate of a tamarind polysaccharide (Whistler, 1991; Singer, 1994). Patil and Nadagoudar (1997) reported that polysaccharides derived from tamarind kernel powder were found to be suitable substitutes for corn steep liquor in the production of penicillin. The glucosyl transferase inhibitor, extracted from tamarind husks, was found to
have an anti-dental caries effect (Tamura et al., 1996) and tamarind kernel powder is an ingredient of several cosmetic preparations.

22.2 Fruit growth and ripening

22.2.1 Fruit growth, development and maturation
Tamarind fruit goes through growth, maturation and ripening stages before being ready for harvesting. Tamarind pulp shows a change in color during the different developmental stages; in the case of sweet tamarind, the pulp color changes from yellowish green at the half-ripe stage, and to reddish brown at the fully-ripe stage. Also, the pulp shrinks due to loss of moisture and becomes sticky, the immature pods have green and tender shells and the seeds are soft and whitish. As the pods mature, the shell develops into a brown color, the pulp turns sticky and brown or reddish-brown, and the seeds become harder and darker. When fully ripe, the shells become brittle and easily broken. Fruit ripening is characterized by an increase in the total acidity, sugars and alcohol insoluble materials of the pulp (Hernandez-Unzon and Lakshminarayana, 1982b). Total ash, phenolics and pectins increase in the peel but decrease in the pulp.

22.2.2 Respiration, ethylene production and ripening
Tamarind fruit is non-climacteric (Yahia, 2004); it produces little or no ethylene and there is no large increase in CO₂ production. The maximum CO₂ production occurs four weeks after fruit set and gradually declines thereafter (Hernandez-Unzon and Lakshminarayana, 1982b). The pods reach the ripening stage in 8–10 months after flowering while the fruit is fully ripe when up to half of its original water content is dehydrated. Dehydration begins 203 days after fruit set and may continue to the 245th day (Chaturvedi, 1985). Fruit pods are harvested green for flavoring, and ripe for processing. The fruits of the sweet type are also harvested at two stages, half-ripe and fully-ripe.

22.3 Maturity and quality components and indices
A tamarind tree takes more than seven years to start fruiting and 10–12 years to produce economically appreciable amounts of fruits. Tamarind fruit growth is a typical sigmoid type (Hernandez-Unzon and Lakshminarayana, 1982a). The fully ripened fruits can remain on the tree until the next flowering period without showing any significant deterioration in quality (Rama Rao, 1975); however, they can be subjected to bird and insect attack. The physical separation of the peel from the pulp results from the loss in water content. It is recommended that fruit be harvested when the moisture content is less than 20% to facilitate the separation of the shell from the pulp. Pods from the same tree do not reach maturity at the same time, which makes selective harvesting a necessity.

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22.4 Preharvest factors affecting fruit quality

22.4.1 Rainfall
The tamarind tree is well adapted to semiarid tropical conditions and grows well with an evenly distributed mean annual rainfall of 500–1500 mm (FAO, 1988; Jama et al., 1989; Hocking, 1993). In areas where annual rainfall is less than 500 mm, the trees are usually located near the water table or along water courses. The minimum annual rainfall which tamarind can tolerate is 250 mm and the maximum is up to 4000 mm in well-drained soil (Duke and Terrell, 1974). Tamarind grows well under wet conditions but does not flower (Allen and Allen, 1981; Morton, 1987) as dry weather is important for flowering and fruiting. It produces more fruit when subjected to a fairly long annual dry period (Allen and Allen, 1981; von Maydell, 1986) as a deep and extensive root system helps the tree to grow in very dry areas and withstand up to six months of drought (Coronel, 1991). This can be observed in the north and south dry zones of Sri Lanka, where there is a prolonged dry season of over 4–6 months. In dry zones the bearing ability of tamarind is comparatively less than those grown in intermediate rainfall areas as a sharp drop in rainfall and air temperature increases the curving of tamarind pods due to the low moisture content. Tamarind is usually evergreen but may shed its leaves in very dry conditions during the hot/dry season (Morton, 1987).

22.4.2 Temperature
Tamarind grows within an annual temperature range of 33–37 °C and at a minimum temperature of 9.5–20 °C. Older trees can withstand temperatures as high as 47 °C and as low as −3 °C without serious injury (Verheij and Coronel, 1991). Tamarind may not survive in an altitude higher than 2000 m (Roti-Michelozzi, 1957; Dale and Greenway, 1961; Brenan, 1967; FAO, 1988; Jama et al., 1989), probably because of the low temperature rather than the altitude itself. It is very sensitive to fire and frost and requires protection when small (Troup, 1921; NAS, 1979) and is a light-demanding tree. The strong and pliant branches and deep and extensive root system make the tree wind-resistant (Coronel, 1986) and it is therefore known as the hurricane-resistant tree (NAS, 1979; von Maydell, 1986; von Carlowitz, 1986).

22.4.3 Soil
The tamarind tree can grow in a wide range of soils and has no specific soil requirement (Chaturvedi, 1985; Sozolnoki, 1985; Galang, 1955). The tamarind tree has the ability to grow in poor soils because of its nitrogen fixing capability (Felker, 1981; Felker and Clark, 1980) and it can grow on rocky soil too. In India and Thailand, tamarind has been reported to grow on sodic and saline soils and on degraded land as well (Anon, 1991; Nemoto et al., 1987). Old tamarind trees have been found growing close to the sea (NAS, 1979; Pongskul et al., 1988;
Anon, 1991). Pot experiment results showed that tamarind can grow in soil containing up to 45% exchangeable sodium (Dwivedi et al., 1996). El-Siddig et al. (2004a, 2004b) found a slight delay in emergence, but no effect on seedling growth, with up to 30 mM NaCl salinity, while Gebauer et al. (2001) reported that tamarind seedlings can tolerate salinity up to 80 mM NaCl. It prefers soils that favor the development of a long tap root (Galang, 1955; Kelly and Cuny, 2000; Rao et al., 2000). Tamarind does not withstand low water-drainage soil (Relwani, 1993; Vogt 1995). The optimum pH is slightly acidic, 5.5–6.8 (FAO, 1988), though it also grows well in alkaline soils (Singh et al., 1997, quoted from Rao et al., 1999). It has been suggested that the association of tamarind with ant-hills and termite mounds may be due to a preference for slight lime content (Jansen, 1981) and aerated soil (Dalziel, 1937; Eggeling and Dale, 1951; Irvine, 1961; Allen and Allen, 1981).

22.5 Diseases and pests and their control

Tamarind fruits are subject to pests and diseases but are usually very tolerant to pathogens and insects, except in large plantations, because of their low moisture content and high content of acids and sugars. Also, the high phenolic content in the peel makes the fruit highly resistant to attacks from pathogens. Pulp separated from peel has good keeping quality but is subject to various molds in refrigerated storage.

There are more than fifty insect pests that have been reported to attack tamarind in India (Joseph and Oommen, 1960; Senguttavan, 2000). These pests attack the tamarind tree at different growth stages; in the nursery as seedlings, and in the field once mature. They also attack different parts of the tree including stem, bark, branches, leaves, flowers and fruits. Fruits are attacked at different stages of ripening before and after harvesting. All these pests and diseases are of different economic importance, causing reduction in fruit production to different extents. In humid climates, fruit are readily attacked by beetles and fungi, and should therefore be harvested before they are fully ripe.

The most serious pests of the tamarind are hard scale insects that suck the sap of the buds and flowers and accordingly reduce fruit production (Butani, 1978). The most important of these is the oriental yellow scale insect (Aonidiella orientalis). These scale insects can be controlled by removing the affected parts of the tree at an early stage while serious infestation can be controlled effectively using pesticides such as Diazinon or Carbosulphan at 0.1% solution (Butani, 1979). The mealy-bugs Nipaecoccus viridis and Planococcus lilacinus suck the sap of leaflets, causing defoliation, and may feed on young fruits; Chionaspis acuminata-atricolor and Aspidiotus spp suck the sap of twigs and branches. Mechanical control of mealy bugs can be achieved by removing the infected parts, but when serious infestations take place, chemicals such as Diazinon or Carbosulphan at 1% solution can be sprayed (Butani, 1979). Caterpillars, Thosea aperiens, Thalarsodes quadraria, Stauropus alternus, and Laspeyresia palamedes;
the black citrus aphid, *Toxoptera aurantii*; the white fly, *Acaudaleyrodes rachispora*; thrips, *Ramaswamia hiella subnudula, Scirtothrips dorsalis,* and *Haplothrips ceylonicus*; and cow bugs, *Oxyrhachis tarandus, Otinotus onerotus,* and *Laptoentrus obliquis,* and other predators attack tamarind leaves or flowers. Other important pests that attack tamarind include fruit borers such as larvae of the cigarette beetle, *Lasioderma serricorne,* also of *Virachola isocrates, Dichocrocis punctiferalis, Tribolium castaneum, Phycita orthoclinia, Cryptophlebia (Argyroplaca) illepide,* *Oecadarchis* sp., *Holocera pulverea, Assara albicostalis, Araecerus suturalis* and *Aephitobius laevigiatius.* The fruit borer *Aphomia gularis,* the tamarind beetle *Pachymerus (Coryoborus) gonogra* and the tamarind seed borer *Calandra (Sitophilus) linearis* attack ripening pods before and after harvest. The rice weevil *Sitophilus oryzae,* rice moth *Corcyra cepholonica,* and the fig moth *Ephestia cautella* infest the fruits during storage. The borer *Rhyzopertha dominica* infests tamarind seeds during storage. Larvae of the groundnut bruchid beetle are serious pests that attack the fruit and seed in India while Bacterial leaf-spot is caused by *Meliola tamarindi.* Rots attacking the tree include saprot (*Xylaria euglossa*) brownish saprot (*Polyporus calcutensis*), and white rot (*Trametes floccosa*). The tamarind tree is also susceptible to nematodes (e.g. *Xiphinema citri* and *Longidorus elongates*) that attack the roots of older trees. Other minor pests in India include lac insect and bagworms.

### 22.6 Postharvest handling factors affecting quality

#### 22.6.1 Temperature management

Storage for long periods under poor conditions, such as exposure to extremes of temperature and humidity, causes gradual changes in color from brown or yellowish-brown to black colors (FAO, 1989). Also, high temperatures cause pulp to lose moisture and become sticky and curved.

#### 22.6.2 Water loss

Drying the fruits in the sun for 3–4 days is used to remove excess moisture and prevent the growth of molds. However, severe dehydration associated with sharp water loss causes curving of the fruits which are considered of lower quality compared to straight pods (Yahia, 2004).

#### 22.6.3 Physical damage

The main problem with fresh sweet tamarind is the damage caused by packaging, which deteriorates the fruit quality and reduces the amount of consumable fruit. Also harvesting the fruits, which is usually done by shaking the branches, might result in fruit damage. A better quality of fruit could be obtained by using scissors to harvest the fruits, especially in the case of the sweet tamarind type.
22.7 Postharvest handling practices

22.7.1 Harvest operations
Pod yield stabilizes at about 15 years and continues for up to 50 or 60 years. Tamarind fruits are mature and ready for harvesting when a hollow and loose sound is produced by finger pressing, as the pulp shrinks with maturity and the shell becomes brittle. Also, the change in testa color might indicate the maturity of the fruit. However, it is not always easy to determine whether the fruits are ready for harvesting, as the testa color only changes slowly as the pods mature. Individual fruits on the same tree also mature at different times, making selective harvesting necessary. Pods are harvested at different stages of ripeness, according to how they are going to be used. Immature green fruits are usually harvested earlier for flavoring. In most countries, the sour tamarind ripe fruits are usually gathered by shaking the branches and collecting the fruits that have fallen; the remainder of the fruit is left to fall naturally when ripe. Sweet tamarind fruits tend to gain higher market prices, and therefore are carefully picked by hand. To avoid damaging the pods and to increase the marketability of both sweet and sour types, harvesting by clipping should be practiced (Coronel, 1991). Pickers should not knock the fruits off the tree with poles, as this will damage developing flowers and leaves. Generally, the fruits are left to ripen on the tree before harvesting, so that the moisture content is reduced to about 20%. If unharvested, the pods may remain hanging on the tree for almost one year after flowering and sometimes until the next flowering period (Chaturvedi, 1985), and eventually will fall naturally. Fruits for immediate processing are often harvested by pulling the pod away from the stalk, which is left with the long, longitudinal fibers attached. Beetles and fungi readily attack ripe fruit in humid climates, and therefore they should be harvested before they are fully ripe.

22.7.2 Packinghouse practices
One of the most important operations in a packing line is sorting for maturity, color, shape, size, and defects. The efficiency and effectiveness of sorting govern the quality standard of the packing lines and product (Office of Thai Agricultural Commodity and Food Standard, 2003), which in turn determines the marketability of the product. Manual sorting continues to be the most prevalent method used, although it is costly in terms of labor and time. Also, the lack of trained labor is one of the reasons that manual sorting may become inefficient and cause damage. One of the most practical and successful techniques for nondestructive quality evaluation and sorting of agricultural products is the electro-optical technique, which judges the optical properties of the product (Chen, 1996). This technique, which can be used to detect color uniformity, shape, size, external defects, foreign materials, and disease, has been used for postharvest grading for a wide variety of agricultural products including tamarind. Jarimopas et al. (2008) proposed packaging in a sleeve design, 15 cm in diameter by 20 cm in height, containing a mixture of 5 mm foam balls and sweet tamarind inserted vertically. This packaging
imparts 15 to 16% of the damage of conventional packaging and costs half the price.

22.7.3 Control of ripening and senescence
Tamarind fruit, as a non-climacteric (Yahia, 2004), will not ripen any further after harvest. The flavor, juice, sugars and some other contents remain unchanged. No information is readily available on techniques for controlling tamarind ripening.

22.7.4 Recommended storage and shipping conditions
The high soluble solids content to titratable acidity (SSC : TA) and the low water content of tamarind fruit contributes to its long storage-life. Tamarind can be stored with the shell, or as a separated dry pulp, and tightly packaged pods can be stored at 20 °C for several weeks. The pulp of mature tamarind is commonly compressed and packed in palm leaf mats or plastic bags and stored at 20 °C for a significant period when processed into paste. It can be frozen and stored for one year, or refrigerated for up to six months. Under dry conditions the pulp remains good for about one year, after which it becomes almost black. In humid weather, especially, the pulp becomes soft and sticky as pectolytic degradation takes place and moisture is absorbed (Lewis and Neelakantan, 1964a; Anon, 1976). During storage, the dry, dark-brown pulp becomes soft, sticky, and almost black. The pulp can be stored for a longer period after drying or steaming. According to the research findings of CFTRI (Central Food Technological Research Institute, Mysore, India), the pulp could be preserved well for 6–8 months, without any treatment, if it is packed in airtight containers and stored in a cool dry place (Shankaracharya, 1997). The tamarind kernel powder is liable to deterioration during long storage, particularly in a moist environment; thus a dry place in moisture proof containers is preferred, after suitable fumigation. The powder may be mixed with 0.5% of sodium bisulphite before packing to prevent enzymic deterioration (Anon, 1976).

22.8 Processing
22.8.1 Processing of tamarind pulp
Fresh-cut processing is not an industrial practice: it is usually carried out on a smaller scale when the fruits are intended to be eaten immediately. Fresh-cut tamarind is processed to make tamarind balls mixed with sugar after removing the shells, seeds and fibers. In Asia, the immature green pods are often eaten dipped in salt as a snack. In the Bahamas the unripe pods are roasted in coal, peeled back and the sizzling pulp is dipped in wood ash and eaten.
In processing factories, tamarind pulp is separated from the fiber and seed, then mashed with salt before being packed into bags and if tamarind is intended to be stored for a long period, drying or freezing is required. To preserve tamarind,
the fruit are shelled, layered with sugar in boxes or pressed into tight balls and covered with cloth and kept in a cool and dry place. For shipment, tamarinds may be shelled, layered with sugar in barrels and covered with boiling syrup. East Indians shell the fruit and sprinkle them lightly with salt as a preservative. In Java, the salted pulp is rolled into balls, steamed and sun-dried, then exposed to dew for a week before being packed in stone jars. In India, the pulp, with or without seeds and fibers, may be mixed with salt (10%), pounded into blocks, wrapped in palm-leaf matting, and packed in burlap sacks for marketing. To store for long periods, the blocks of pulp may be first steamed or sun-dried for several days.

During pre-processing, fresh tamarind fruit is subjected to sun-drying or small scale dehydrators are sometimes used. The dry fruit is cracked, the pulp and fibers are separated and the seeds are removed. Pods can be store for several weeks at 20 °C. Also, pulps can be stored for 4–6 months at 10 °C by packing in high density polythene. Mixing with salt can extend the storage period to one year.

Tamarind juice is usually prepared by boiling tamarind pulp in water and filtering the juice to remove the pulp before pouring into bottles and sealing. Tamarind concentrate is easily dispersible in water, and can be used for many purposes, such as in ketchups, sauces, soft drinks, dairy products and as a souring agent. It is prepared by soaking the tamarind pulp in water and boiling, separating fine and pulpy matter using a filter, then pressing the residue and mixing this with the extract. The filtered extract is concentrated by evaporating it in a vaccum, filling containers, cooling and sealing, and storing in airtight plastic or glass bottles or cans, in the dark, for over a year.

Tamarind is often further processed into drinks and sweets or packaged into more convenient forms for export. In some parts of India, it is made into a jelly by mixing with water and sieving. It is then compressed into moulds and can be cut like cheese when required.

22.8.2 Processing of tamarind seed
The hard, brown outer testa has to be completely removed from the kernel to prevent it from causing undesirable effects such as depression, constipation, and gastrointestinal inflammation, so the testa is separated from the kernels by either roasting or soaking the seed in water. Washing the seeds helps to remove the adhering pulp and to float away partially hollow infected seeds. When roasting, the temperature and duration of heating should be controlled to avoid the development of any undesirable characteristics in the isolated gum (Anon, 1976). The parched seed is then fed into a grain cleaner to remove the testa and dirt (Whistler and Barkalow, 1993). Very white tamarind kernel powder can be obtained by hydrating the seeds at room temperature for 24 hours, drying in the shade for 24 hours and then sand roasting at 125–175 °C for 3–8 minutes. Different processing methods to remove the testa were reported by Kumar and Bhattacharya (2008).
22.9 Conclusions

The intrinsic value of raw tamarind can be further enhanced through value addition activities and there is a good market for these processed products both in the domestic as well as in international markets.

22.10 References


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