13 Tamarind (*Tamarindus indica* L.)

Abstract

Tamarindus indica L. is a member of the dicotyledonous family Fabaceae of subfamily Caesalpinioideae having five to nine tribes based on morphology. Cultivation of tamarind started in Egypt as early as 400 BC. The tree is also mentioned in the Indian Brahma Samhita scriptures between 1200 and 200 BC and in Buddhist sources from around the year 650 AD.

In recent times identification of superior types of varieties has led to regular plantation of the crop all over India.

India is the world's largest producer of tamarind products. In India, it is naturally regenerated on wastelands and forest lands. Since ancient times, India has been exporting processed tamarind pulp to Western countries, mainly the European and Arab countries and more recently the USA.

13.1 Introduction

Cultivation of tamarind occurred in Egypt as early as 400 BC. The tree is also mentioned in the Indian Brahma Samhita scriptures between 1200 and 200 BC and in Buddhist sources from around the year 650 AD (Salim et al. 1998). The name tamarind is derived from the Arabic Tamar-u'l-Hind because the dark brown pulp of the fruit was thought to resemble dried dates. It was therefore called the Tamere-Hindi or the "date of India." According to Coates-Palgrave, this inspired Linnaeus in the eighteenth century to name the tree as *Tamarindus indica*. According to a Native American legend, the tree existed in Ecuador in the pre-Colombian era (FAO 1988).

13.2 Area

At present tamarind is cultivated in 54 countries of the world; 18 countries in its native range and 36 other countries where it has become naturalized. The major areas of production are in the Asian and American continents. In most countries, tamarind is a subsistence tree crop mostly meeting local demands, although some of it is also exported. The major product is the fruit which is used for culinary purposes, making juices, chutneys, sauces, etc., while the seed is the main component used in industrial applications. The timber is hard having little commercial value but is used at the local level for making furniture and tools and used as fuelwood.

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India is the world's largest producer of tamarind products. In India, it is naturally regenerated on wastelands and forestlands. Since ancient times, India has been exporting processed tamarind pulp to Western countries, mainly the European and Arab countries and more recently the USA.

More recently, Thailand has become a major producer of tamarind, with sweet and sour varieties in production. Thailand is particularly prominent due to the availability of the sweet-tamarind types. Many other countries have minor production areas of tamarind and depend on wild trees established through natural regeneration.

13.3 Taxonomy

Tamarindus indica L. is a member of the dicotyledonous family Fabaceae of subfamily Caesalpinioideae having five to nine tribes based on morphology. It is a diploid species with chromosome number of $X=12$ and $2n=24$ (Purseglove 1987). According to Leonard (1957), the *Amherstieae* has a total of 25 genera, 21 in tropical Africa, 2 in tropical America, and 2 in Asia. Both *Tamarindus* and *Amherstia* are derived, with zygomorphic and showy flowers and stamen filaments connate in a sheath, but have many differences in the floral structure, leaves, fruits, and seeds. *Tamarindus* is said to have some resemblance to *Heterostemon Desf.* from the upper Amazon region of South America. No other tree bearing any resemblance to tamarind has been reported in other countries.

13.4 Vegetative Characters

Tamarind is a long-lived, large, evergreen, or semi-evergreen tree, up to 30 m tall. The trunk can be up to 8 m in circumference, with a spreading, rounded crown, up to 12 m in diameter. The tree has a poor form, the bole splitting at about 1 m from the ground and often multi-stemmed, though it has fairly good coppicing ability. The trunk is short fissured with bark light gray to brown, very rough and scaly; the inner bark is 1–2 cm thick and green white in color. The branches are often crooked, thick, wide spreading, and drooping at the ends to form a dense crown (Storrs 1995). The blood-red-colored gum exudes from the bole and branches when they are damaged. It has a maximum height of 30 m (Allen and Allen 1981) and maximum tree diameter of 4.1 m (Gamble 1922). Long-lived tree reported 150 years in India.

13.4.1 Wood

Bright yellow sapwood and brown violet heartwood; it is dense, very hard, and close grained and takes a fine polish. Resistant and durable but susceptible to termite attack.

13.4.2 Root

In most locations tamarind produced a deep taproot, except in poorly drained or compacted soils, and has an extensive lateral root system. The main root is wiry and flexuose, while the lateral roots are numerous, moderately long, and distributed down the main root. In its seedling, the hypocotyl is distinct from and thicker than the root, 3.8–8.9 cm long, slightly compressed and finely tomentose.

13.4.3 Leaves

These are alternate, even, and paripinnately compound, 7–15 cm long with a pulvinus at the base and 6–20 pairs of opposite leaflets. The leaflets are $12–32 \times 3–11$ mm in size, narrowly oblong, unequal and entire, rounded or slightly emarginate at the apex, and rounded at the base; they are glabrous or slightly puberlous, glaucous beneath and darker green above with reticulate venation, and are sessile to sub-sessile. The apex is rounded to almost square, slightly notched and asymmetric with a tuft of yellow hairs. A prominent scar is seen after leaf fall. Tropism is observed in tamarind; the leaflets fold after dark.

13.4.4 Inflorescences and Flowers

The inflorescence racemes are small, 5–10 cm long, terminal and lateral drooping, and often panicled. The flowers are bisexual and 2–2.5 cm in diameter. Pedicels are about 5 mm long, nodose and jointed at the apex.

13.4.5 Pollen and Seed Dispersal

The presence of nectar in the tamarind flower suggests that pollination is carried out by insects (Prasad 1963). The structure of the flower however does not exclude the possibility of self-pollination, which can also result in seed set. The large, hard seeds are dispersed by both animals and man.

13.4.6 Pollination and Fruit Set

Thimmaraju et al. (1977) reported that tamarind is protogynous, entomophilous, and highly cross-pollinated. They also reported that flower bud development takes about 20 days from first visible initiation.

13.4.7 Fruit

The fruit is pendulous; pods are 5–10 cm × 2 cm, oblong or sausage-shaped, curved or straight with rounded ends. The shell is light grayish or scurfy brown and filled with soft pulp surrounding the seed cavities (Coronel 1991).

13.4.8 Seed

Pods contain 1–10 seeds, each 3–10 × 1.3 cm, irregularly shaped, flattened and rhomboid. The seeds are very hard, shiny, reddish or purplish brown, and non-arillate exalbuminous. There are about 720 seeds per kg of fruit (Hong et al. 1996).

13.5 Climate

Tamarind is adapted to a wide range of ecological conditions, reflecting its wide geographical distribution in the sub- and semiarid tropics. It grows wild in many countries and is also widely cultivated. According to Dalziel (1937), the tree has an abundant leaf fall and usually has no undergrowth. Although the tree is often planted for its pleasant shade in villages, people in India object to sleeping under the tree, as they fear the "harmful acid exhalations." The leaves bear acid exudation droplets, which refresh the air at hot times of day (Jansen 1981). Joshi (1985) has suggested that tamarind is a weather-indicating plant of tribals in Rajasthan, India.

13.6 Temperature

Essentially a tree of tropical climates, tamarind thrives under a maximum annual temperature ranging from 33 to 37 °C and a minimum of 9.5–20 °C. Trees are very sensitive to fire and frost and require protection when small. Older trees are resistant to extremes of temperature than young trees and can withstand temperatures as high as 47 °C and as low as −3 °C without serious injury. Tamarind is more cold tolerant than mango, avocado, and lychee (Verheij and Coronel 1991).

13.7 Light

It is a light-demanding tree. The ground is usually bare around the tree due in part to the dense shading by the canopy.

13.8 Soil Requirements

It is growing in a wide range of soils and has been suggested that no other specific requirements needed. With little or no cultivation, it can flourish in poor soils and on rocky terrain. In India, it tolerates sodic and saline soils where it grows in ravines and on degraded land. The optimum pH for tamarind is 5.5–6.8, which is slightly acidic, though it also grows well in alkaline soils.

13.9 Uses

13.9.1 Domestic Uses

Production of tamarind for home consumption in home gardens and small waste areas would assist in providing nutrition security, especially in drought-prone regions where fresh fruit is a small component of the daily diet.

13.9.1.1 Pulp

It is the most valuable and commonly used part of the tamarind. The pulp constitutes 30–50 % of the ripe fruit (Purseglove 1987), the shell and fiber account for 11–30 %, and the seed about 25–40 % (Chapman 1984). Fruit composition is variable, depending on locality. Tamarind has low water content and a high level of protein, carbohydrates (60–72 %), and minerals. The soluble content varies from 54 to 69.9° Brix. The pulp contains oil, which is greenish in color, and liquid at room temperature. The major constituents of it include furan derivatives and carboxylic acids. It contains tartaric acid ranging from 12.2 to 23.8 %, which is uncommon in other plant tissues. It contains 25–45 % reducing sugars, of which 70 % is glucose and 30 % is fructose. Ascorbic acid content of tamarind is very small and varies from 2 to 20 mg/100 g. Other organic acids are also present like oxalic acid, succinic acid, citric acid, and quinic acid. According to Lakshminarayan Rao et al. (1954) about 55 % of the total nitrogen in the tamarind pulp was non-protein N or soluble in 10 % trichloroacetic acid, and 70 % of this is contributed by free amino acids. It is also rich in minerals.

13.9.1.2 Seeds

It comprised the seed coat or testa (20–30 %) and the kernel or endosperm (70–75 %) (Coronel 1991; Shankaracharya 1998). Tamarind seed is a raw material used in the manufacture of tamarind seed kernel powder, polysaccharide, adhesive, and tannin. They are alternative source of protein, rich in some essential amino acids. Unlike the pulp, the seed is a good source of protein and oil. Whole tamarind seed and kernels are rich in protein (13–20 %), and the seed coat is rich in fiber (20 %) and tannins (20 %). Panigrahi et al. (1989) reported that whole tamarind seed contains 131.3 g/kg crude protein, 67.1 g/kg crude fiber, 48.2 g/kg crude fat, and 56.2 g/kg tannins. About 70 % of the proteins were extractable. The protein isolated was relatively high in lysine, phenylalanine, tyrosine, and leucine. Albumins and globulins constitute the bulk of the seed proteins. The seed is rich in cystine and methionine but threonine and tryptophan are limiting. It has a very good balance of essential amino acids. The seed kernel is rich in phosphorus, potassium, and magnesium.

13.9.1.3 Seed Kernel Oil

The seed oil is golden yellow, semidrying oil, which in some respects resembles groundnut oil. Andriamanantena et al. (1983) extracted the oil with hexane and a mixture of chloroform and methanol; the yield was 6.0–6.4 % and 7.4–9.0 %, respectively.

13.9.1.4 Leaves and Flowers

The leaves are used as vegetable by endemic peoples in producing countries. They contain 4.0–5.8 % proteins, while the flowers contain only 2–3 %. The leaves are also a fair source of vitamin C and beta-carotene and the mineral content is high, particularly in potassium, phosphorous, calcium, and magnesium. The leaves are also used as fodder for domestic and wild animals, including elephants.

13.9.1.5 Wood

Tamarind wood is used for many purposes including making furniture, wheels, mallets, rice pounders, mortars, pestles, plows, well construction, tent pegs, canoes, side planks for boats, cart shafts and axles, and naves of wheels, toys, hubs, oil presses, sugar presses, tools and tool handles, turnery, etc.

The wood also makes good fuel with a calorific value of 4,850 kcal/kg, producing great heat, which is required in brick making. The wood makes excellent charcoal, is valued for making gun powder (NAS 1979; Chaturvedi 1985), and used as a major fuel to produce gas units that powered Indian cars and trucks during World War 2.

13.9.2 Medicinal Uses

Tamarind products, leaves, fruits, and seeds have been extensively used in traditional Indian and African medicine.

13.9.2.1 Pulp

It is used in Africa, Asia, and America. In former times, the fruit pulp was used as a gentle laxative under the name "pulpa tamarindorum." Tamarind pulp alone or in combination with lime juice, honey, milk, dates, spices, or camphor is used as a digestive even for elephants.

Tamarind pulp is also said to aid in the cure of malarial fever (Timyan 1996). The pulp is also effective in ridding domestic animals of vermin in Colombia through the application of pulp with butter and other ingredients (Morton 1987).

13.9.2.2 Seed

The seed is usually powdered and often made into a paste for the treatment of most external ailments. In Cambodia and India, it has been reported that powdered seeds have been used to treat boils and dysentery.

Seed powder has also been externally applied on eye diseases and ulcers; boiled, pounded seeds are reported to treat ulcers and bladder stones and powdered seed husks are used to treat diabetes (Rama Rao 1975). The seed can also be used orally, with or without cumin seed and palm sugar, for treatment of chronic diarrhea and jaundice.

13.9.2.3 Leaves

Tamarind leaves are usually ground into powder and used in lotions or infusions. The leaves, mixed with salt and water, are used to treat throat infections, cough, fever, intestinal worms, urinary troubles, and liver ailments. Leaf extracts also exhibit antioxidant activity in the liver. Also taken internally, the leaves are used in cardiac and blood sugar reducing medicines.

The leaves are also used to treat ulcers, and the juice of the leaves, boiled with oil, is applied externally to treat rheumatism and external swellings in the Philippines and West Africa (Jayaweera 1981; Rama Rao 1975).

13.9.2.4 Bark, Flower, and Root

The medicinal properties of the bark, flower, and root are similar in many respects to the pulp. Treatments for digestive tract ailments and indigestion have been reported from Cambodia, India, and the Philippines. The bark is the usually the most effective method of administration. The bark has also been used to recover loss of sensation due to paralysis. Gargling the ash with water has been used in the treatment of sore throat. The bark is astringent and used as a tonic and in lotions or poultices to relieve sores, ulcers, boils, and rashes in the Philippines and eastern Sudan (Dalziel 1937). The poultice of flower is used in the treatment of eye diseases and conjunctivitis in the Philippines (Brown 1954).

13.9.3 Industrial Uses

Tamarind pulp is used as a raw material for the manufacture of several industrial products, such as tamarind juice concentrate (TJC), tamarind pulp powder (TPP), tartaric acid, pectin, tartarates, and alcohol (Anon 1982a).

13.9.3.1 Tamarind Kernel Powder

The major industrial use of the seeds is in the manufacture of tamarind kernel powder (TKP). It is prepared by decorticating the seed and pulverizing the creamy white kernels. The decorticated seed is ground to the required mesh size by machines to obtain a yield of 55–60 %.

Mixing with sodium bisulfate before packing will prevent enzymatic deterioration. It should have flavoring characteristics when dissolved in water and be free of any burnt or other undesirable flavors.

13.9.3.2 Pectins

Polysaccharides obtained from tamarind seed kernels form mucilaginous dispersions with water and possess the characteristic property of forming gels with sugar concentrates, like fruit pectin. However, unlike fruit pectin, tamarind polysaccharide can form gels over a wide pH range, including natural basic conditions. Jellose is prepared on a large scale by adding TKP to 30–40 times its weight of boiling water, containing citric or tartaric acid at a concentration of 0.2 %.

13.9.4 Other Uses

Tamarind pulp mixed with sea salt has been reported to polish brass, copper, and silver in Sri Lanka (Jayaweera 1981), India (Benthall 1933), West Africa (Morton 1987), South Africa, and Somalia. The seed testa contains 23 % tannin, which when suitably blended is used for tanning leather and imparting color-fast shades to wools. The fruits are reported to have antifungal and antibacterial properties (Guerin and Reveillere 1984). The seed husk has also been found to be an effective fish poison (Roy et al. 1987). Tamarind extract has also been reported to have an inhibitory effect on plant virus diseases. In India, extracts obtained from tamarind plant parts have completely inhibited the activity of both cowpea mosaic and the mung bean mosaic viruses (Singh et al. 1989). Antioxidant activity of tamarind seed was investigated by Osawa et al. (1994). The seed is also used as filler for adhesives in the plywood industry.

13.10 Genetic Resources

13.10.1 Genetic Resources of Tamarind

Plant genetic resources are basic raw materials for improvement of any crop plant. The wider genetic diversity is fundamental for the development of new varieties with good quality and higher yields (Frankel and Hawkes 1975). The genetic variation of tamarind has been based on the phenotypic variation observed. This is primarily based on fruit characteristics, such as length of pod, pod weight, seed number, pod color, and sweetness of pulp. Recent evidence also indicates the existence of variation of characteristics of fruit pulp in different countries, some with less acid or sweet fruits. The variations have also been reported for tolerance to drought, wind, poor soils, waterlogging, high and low pH, and grazing. Phenological diversity also exists in tamarind, and tree to tree variations are common in flowering and in maturing fruits (Mahadevan 1991), which may reflect either genetic variation or genotype x environmental interactions and/or both. Wide phenotypic variation in tamarind germplasm has been attributed to geographic isolation and gene mutation (Feungchan et al. 1996a). The origin of a sweet tamarind has been attributed to a point mutation.

13.10.2 Evaluation of Germplasm (Table 13.1)

Table 13.1 General characteristics useful to distinguish tamarind cultivars

Plant part	Character
Flower	Color of petals (dark pink to whitish cream)
	Flowering pattern (early-late)
Pod	Pod form, length, breadth, curvature, shape, pod size, pod weight, color of shell
Pulp	Color (red/whitish), pulp/shell ratio
	Real pulp value, pulp yield/pulp recovery %
	Fiber content, ease of pulp extraction
Seed	Color, size, weight, number of seeds per pod, seed/pulp ratio
Yield	Total yield of pods, alternate/regular bearing habit
Biochemical	Sweetness of pulp (ratio of tartaric acid/sugar/protein and mineral constituents, amino acid composition)
Others	Resistance to salinity, drought, degraded soils, waterlogging, high pH, low pH, grazing diseases and pests, tree form

13.10.3 Germplasm Evaluation in India

In India, most of the area under tamarind cultivation is planted with unselected, inferior cultivars. The Bharata agricultural and industrial foundation (BAIF), Pune, India, has attempted to supply improved planting material to smallholders by selecting superior trees from among the existing natural populations. The parameters for selection of superior trees have been based entirely on pod characteristics such as pod length, pod color, and pulp yield per pod.

The most preferred cultivar is Periyakulam 1 (PKM-1), a sour type, a clonal selection from a local variety of a village named Endapalli near Periyakulam. It has a pulp recovery percentage of 39 % compared to the local cultivars which is 28 %. The yield is also higher. Studies were also undertaken to select high yielding varieties based on their flowering pattern. In seedling populations, early, mid, and late flowering tamarind types have been identified. Recent developments in biochemical and molecular markers could be effectively used to identify the genetic variations within and between tamarind populations.

13.11 Cultivars

- *India*: Pratishthan, Periyakulam (PKM 1), Urigam. Under semiarid conditions of Gujarat, India, promising genotypes (24) of tamarind were collected and evaluated for growth, flowering, fruiting, and fruit quality attributes. The maximum number of fruits per panicle was recorded in Pratishthan (4.00), closely followed by Goma Prateek (3.50), Sweet Type (3.20), and T-263 (3.00). Peak period of ripening time in majority of genotypes was March. Maximum fruit yield per plant (85.00 kg) was recorded in Goma Prateek during the 12th year of orchard life under rainfed conditions of hot semiarid ecosystem, closely followed by T-10 (43.00 kg/plant), while minimum was recorded in PKM-1 (12.00 kg/plant).

13.11.1 Brief Characteristics of Tamarind Cultivars

13.11.1.1 Tamarind-13

Plant height is 4.7 m, stem girth 63.66 cm, plant spread N-S 7.52 m, and E-W 7.43 m. Tree form spreading type, leaves opposite, mostly firm and glossy, elliptic, pinnately veined. Flowering initiation of bloom starts from the last week of May, full bloom in the first week of June, and end bloom in the fourth week of June. Mean length of panicle is 14.81 cm. Ripening time starts from the first week April. Mean fruit yield/plant is 49.83 kg. Pod weight is 26.70 g. Seed weight per fruit is 7.58 g. TSS is 71.00 ° Brix and acidity 14.06 %. Total sugar is 55.81 % and reducing sugar 27.27 %. Protein content is *3.29* g/100 g pulp, calcium 177.70 mg/100 g pulp, magnesium 44.17 mg/100 g pulp, and phosphorus 70.83 mg/100 g pulp.

13.11.1.2 Tamarind T-263

Plant height is 4.66 m, stem girth 6.5 cm, plant spread N-S 7.3 m, and E-W 7.29 m. Tree form spreading type, leaves opposite, mostly firm and glossy, elliptic, pinnately veined. Flowering initiation of bloom starts from the last week of April, full Bloom in the last week of May, and end bloom in the fourth week of June. Mean length of panicle is 10.11 cm. Ripening time starts from the first week April. Mean fruit yield/plant 11.13 kg. Pod weight is 14.94 g. Seed weight per fruit is 7.58 g. TSS is 68.00 ° Brixand acidity 11.15 %. Total sugar is 52.49 % and reducing sugar 25.28 %. Protein content 2.55 g/100 g pulp, calcium 164.31 mg/100 g pulp, magnesium 35.24 mg/100 g pulp, and phosphorus 42.83 mg/100 g pulp.

13.11.1.3 CHEST-10

It has semi-spreading growth habit, thick trunk, and drooping branches. Peak period of ripening time starts the first week of April. It recorded 43 kg fruit yield per plant, pulp percent 52.20 %, and TSS 71.30 °Brix.

13.11.1.4 CHEST-11

It has semi-spreading growth habit, thick trunk, and drooping branches. Peak period of ripening time starts the last week of March. It recorded 22 kg fruit yield per plant, pulp percent 52.10 %, and TSS 71.10° Brix.

13.12 Ex Situ Conservation

Conservation of tamarind germplasm is an important prerequisite to prevent the loss of genetic diversity of this species. Ex situ management is considered to be one of the best and economically and socially acceptable methods for conservation of tamarind germplasm (Singha 1995). In this method, phenotypically superior germplasm is collected from different countries and multiplied through vegetative propagation to be established in clonal orchards. Seed germplasm banks can be maintained since seeds may be stored for longer periods. A low cost method of conserving tamarind germplasm by the establishment of protected areas could also be effective as practiced for the conservation of forest genetic resources in some parts of the world (Collins et al. 1991).

13.13 Genetic Improvement

Recently, genetic improvement using superior clones has been described by Kulkarni et al. (1993). Tamarind has a relatively long generation time and is believed to be primarily outcrossing. In the short term, those trees having superior characteristics could be selected for vegetative propagation by air layering or grafting methods to produce fast-growing trees for local (home gardens) and commercial purpose.

13.13.1 Selection

Therefore, the selection of plus trees is an important step in tamarind tree improvement programs. Plus trees can be selected using the following characteristics: acidity of the pulp, content of tartaric acid and sugar, real value of pulp, pod bearing ability (flowering and fruit maturing), pod size, pulp, fiber and seed weights, and number of seeds. Some of the trees that are selected on this basis are reported to have pods 25 cm long and 5 cm wide (Jambulingam and Fernandes 1986).

7 Year old tamarind tree

Profuse flowering

Bumper fruit harvest

Promising genotype

13.13.2 Ideotypes

It is essential to identify different ideotypes for different purposes, localities, environments, and cultural practices. There is no universal ideotype suitable for all sites and end users.

1. Earliness.
2. Deep root system.
3. Fruit size long.
4. The fruiting season could be longer.
5. Heavy yielder, 600–800 kg/tree/year.
6. Regular bearer.
7. Fleshy, sweet/acidic pulp, high pulp recovery.
8. High in nutrients and fodder value of leaf.
9. Wider adaptability and resistance to pests and diseases.
10. Short statured plants suitable for high density.
11. Very good pulp quality for value addition and export.

13.14 Cultivation

Nowadays with identification of high yielding and regular bearing varieties, the area under tamarind is increasing fast. Regular orchards are being planted on marginal and wasteland. Apart from this, demand from market is also increasing, and at the same time, there is a huge export market available to this fruit.

13.15 Propagation

Tamarind is traditionally grown from seed, though vegetative and tissue culture propagation methods have been developed.

13.15.1 Seed Germination and Propagation

The seed of tamarind is orthodox (Riley 1981 quoted by Hong et al. 1996). Fresh seeds retain viability for at least 6 months when kept at ambient temperature in dry conditions. Seed germination begins within a week following sowing and may take a month to complete. On average, tamarind seeds begin to germinate about 13 days after sowing (Padolina 1931; Galang 1955). The germination capacity of fresh or well-stored tamarind seed is reported to vary from 65 to 75 %. Coronel (1991) stated that, depending on the conditions, germination might vary from 30 to 70 %. Some studies (FAO 1988) indicate that germination can be improved by storing the seed for 6 months before planting.

Experiments have been conducted to improve the germination of tamarind seeds. Masano (1994) compared three seed pretreatments with an untreated control. The result indicated that slicing the seed was the best, with 92 % germination compared to the control (82 %). Slicing the seed also hastened germination. Germination begins after 7 days and completed at 9 days. The other treatments had no positive effect.

Tamarind is normally grown from seed. Seeds should be collected from high yielding trees with well-formed, rounded, fully ripe pods, although they may not come true to type due to outcrossing. Under natural conditions, the seed pods fall from the trees and the seeds germinate naturally on the onset of monsoon. When propagating by seed, mature ripe pods should be collected from the trees in March–April. The best medium for seed germination is sand or soil mixed with cow dung. Seeds may be germinated in nursery beds, seed boxes, pots, or plastic bags. When grown in nursery beds, the recommended spacing is 20–25 cm in both directions. After planting in the field, seedlings should be protected from browsing animals.

13.15.2 Vegetative Propagation

Vegetative propagation is preferable to seed propagation, as seed propagation does not produce true-to-type progenies. It has advantage of producing true-to-type progeny which can be taken from selected, superior, mother trees. The methods include stem cuttings, shield and patch budding, or grafting onto the seedling rootstocks and air layering or marcotting.

13.15.2.1 Stem Cuttings

A technique using softwood terminal cuttings has been developed, and the protocol standardized, by the forest research station at Maddimadugu, Andhra Pradesh, India (Srivasuki et al. 1990).

They are immediately dipped for 10 s in 1,000 ppm of indole butyric acid (IBA) and in 50 % isopropyl alcohol, before being planted in polypropylene tubes containing vermiculate/perlite (1:1) and placed in a mist propagator with 70–80 % humidity. Soft or semi-soft stem cuttings, 15–20 cm long, taken from 1- to 2-year-old branches can also be rooted (Swaminath et al. 1990).

13.15.2.2 Budding and Grafting Methods

Vegetative propagation methods like, shield and patch budding, cleft grafting, whip grafting, approach grafting, and air layering are reliable methods (Purushotham and Narasimharao 1990). For patch budding, seedling rootstocks should be grown in raised beds and transplanted to polythene bags of 25 × 10 cm size, immediately after germination and seedlings may be budded when they are 6–9 months old. This is a suitable method for large-scale multiplication of tamarind. Pathak et al. (1992) reported 96 % and 94 % success, respectively, of patch budding and modified ring budding of 9-month-old seedling rootstocks. Approach grafting is a very reliable method and up to 95 % success can be obtained (Swaminath and Ravindran 1989). For veneer grafting, rootstocks about 6 months old and of uniform size should be selected. It is reported to give about 50 % success (Amin 1978). For softwood grafting, the rootstock seedlings are defoliated and their tops cut off at 15 cm high immediately before grafting. It was shown to be the best grafting method in terms of successful unions and survival rates (Navaneetha et al. 1990).

13.15.2.3 Micropropagation Techniques

Tamarind may be propagated by tissue culture techniques. Shoot tips, cotyledons, and cotyledonary nodes have been used successfully as explants for tamarind tissue culture (Splittstoesser and Mohamed 1991). Tissue culture raised plants have been reported to show better growth in height, branching habit, spread of branches, early flowering and fruiting cycle, with the start of flowering at an average height of 3.7 m. Although these micropropagation techniques have shown promise, none of them has reached the stage of commercialization.

13.15.2.4 In Situ Seed Sowing

Direct sowing of the seed of tamarind can be can be done in the field (Chaturvedi 1985). Seeds may be seen directly to establish plantations, hedgerows, or home gardens. The seed should be planted up to 1.5 cm deep. The planting holes should however have been previously prepared and filled with well-decomposed manure or compost.

13.15.2.5 Spacing

There are no regular orchards of tamarind; the stray plants of seed origin are found in the villages and in the fields. The recommended spacing between plants is 10 m apart. However, looking at the long life span, the spacing can be varied. In parts of India, tamarind is established at 8 m×8 m, 8 m×12 m, or 12 m×12 m (Jambulingam and Fernandes 1986).

13.15.2.6 Time of Planting

The best time for field planting is at the beginning of the rainy season, particularly in seasonally dry regions. This will reduce the need for frequent watering until the plants are firmly established in the soil. Seedling growth in the field is initially fast (about 1.2 m in the first two years) but slows later.

13.16 Management

13.16.1 Pruning and Training

Tamarind requires minimal care except in the very early stages of growth. Tamarind is a compact tree and produces symmetrical branches. Young trees should be trained to allow 3–5 well-spaced branches to develop into the main scaffold structure of the tree. Usually no pruning is done in tamarind; however, old and dried branches need to be removed every year. Apart from this, the very old trees which have become nonproductive should be headed back keeping 15–20 scaffold branches.

13.16.2 Intercropping

In the initial years, vegetatively propagated plants up to 5 years of age and seed origin orchard up to 10 years of age can be intercropped with traditional crops to increase production potential of the unit area. Intercropping may be practiced in order to obtain some income during the early stages of tree growth and until the trees starts bearing. It is good practice to plant short season crops which grow in the rainy season.

13.17 Nutrition

13.17.1 Fertilizers and Manures

No recommendation on fertilizer dosages is available. Trees are known to fruit well even without fertilizer application, due to their deep and extensive root system. In India, inorganic fertilizers are not applied to tamarind trees, but 5 kg of farmyard manure is applied to the planting hole at the time of planting. In Thailand, the commercial growers use inorganic fertilizers, mostly urea.

13.17.2 Nitrogen Fixation

Tamarind being leguminous tree fixes atmospheric nitrogen. Leguminous species are associated with rhizobium bacteria in root nodules which fix atmospheric nitrogen. Very little information is available on nitrogen-fixing bacteria in tamarind compared to other cultivated legumes. Some evidence suggests that it does form a symbiotic association with rhizobium bacteria enabling the tree to fix atmospheric nitrogen under appropriate conditions (Postgate 1979).

13.17.3 Mycorrhizal Associations

Tamarind seedlings inoculated with 13 vesicular arbuscular mahycorhize (VAM) fungi from various sources around the world have been demonstrated to exhibit increased leaf number, plant height, stem girth, biomass, and phosphate and zinc content. Container-grown seedlings of several leguminous species including tamarind were inoculated with three arbuscular mycorrhizal fungi: *Glomus fasciculatum*, *G. mosseae*, and *Gigaspora margarita*.

13.17.4 Irrigation

Irrigation is not normally practiced in tamarind cultivation, but it promotes better growth during establishment and the early stages of growth, especially during the dry seasons (Yaacob and Subhadrabhandu 1995).

13.18 Pest and Disease Management

13.18.1 Pests

Tamarind trees are liable to be attacked by a large number of insect pests. In India alone, 40 insect pests have been reported as attacking tamarind, causing severe economic losses (Joseph and Oommen 1960). Some of the most serious pests in India are the hard scale insects (Timyan 1996). Mealybugs also attack tamarind trees. Nymphs and the females suck the sap on the ventral surface of the leaflets, the base of leaf petioles, tender shoots, and even the mature shoots. Some thrips are reported to attack tamarind flowers. *Scirtothrips dorsalis* Hood is a polyphagous thrip and the adults live for 10 or 15 days and complete 25 overlapping generations per year (Raizada 1965). The other minor pests in India include the bruchid beetle, *Pachymerus gonagra*, is the most serious pest of tamarind in India and Pakistan (Beeson 1941). The lac insect, *Kerria lacca* kerr. while not considered a major pest, is a widely distributed polyphagous insect in India which attacks tamarind stems, twigs, and leaves and many other cultivated and wild plants. Larvae of *Achaea janata* Linn. are reported to cause heavy losses when epidemics of the moth infest flowers in tamarind plantations in Tamil Nadu (Ahmed 1990). Aphids *Toxoptera aurantii* are serious pests that attack tamarind and many other plants. It is a major pest which sucks the sap of tender shoots and leaflets causing them to become distorted and covered with molds growing on the secreted honeydew. Nematodes are also reported to attack tamarind. The major nematodes are *Radopholus similis*, the burrowing nematode, and *Meloidogyne incognita*, a common root knot nematode.

13.18.2 Diseases

Several diseases have been reported to infect tamarind in India, including various tree roots and bacterial leaf spots. The major diseases reported are leaf spot. In Karnataka state, India, stony fruit disease caused by the fungal pathogen *Pestalotia macrotricha* Syd. makes the fruits hard and stony with fibrous structures. A mildew caused by *Oidium* sp. Is a common occurrence in nursery seedling. The disease causes defoliation and early growth is severely retarded.

13.19 Harvesting

Trees grown from seed may take more than 7 years to start bearing and up to 10 or 12 years before an appreciable crop is produced. Well-tended trees grown in open areas will come into bearing early, in about 7 years and less. Grafted trees will however come in to bearing in 3–4 years. Tamarind seed pods fill at maturity, the pulp becomes brown to reddish brown, and the skin becomes brittle and cracks easily. The pods are gathered when ripe and the hard pod shell is removed. The pulp is preserved by placing it in casks and covering it with boiling syrup or packing it carefully in stone jars with alternate layers of sugar.

13.19.1 Harvesting Stage

In the Philippines, fruits are harvested at two stages, green for flavoring and ripe for processing. The fruits of sweet types are also harvested at two stages, half-ripe and ripe. At the ripe stage, the pulp shrinks, due to loss of moisture, and changes to reddish brown and becomes sticky. In most countries, the sour tamarind fruits are harvested by shaking the branches and the pods are collected on a mat. In sweet tamarind, the pods fetch a high price in the local market and are carefully harvested by handpicking. Sometimes bamboo ladders are used to pick the fruits. Generally, the fruits are left to ripen on the tree before harvesting, so that the moisture content is reduced to about 20 %.

13.20 Yield

The yield of tamarind varies considerably in different countries, depending on genetic and environmental factors. Feungchan et al. (1996a) reported that the fruit yields are influenced by environmental and genetic factors, but the age of the tree is not correlated with fruit yield. Recently, Usha and Singh (1996) reported that cross-pollination results in higher fruit set and retention in tamarind than when open or self-pollinated. Fruit set was only 36 % with open pollination and increased to 56 % with cross-pollination. The effect of growth regulators on fruit setting of sweet tamarind indicated that 4 CPA at 15 ppm concentration helped in maximum fruit set of 216 fruits compared to control (81 fruits) (Feungchan et al. 1996b).

13.21 Processing and Storage

The fresh fruits are often dried using small-scale dehydrators; however, in most countries, rural households dry pods in the sun. The shells, fibers, and seeds are then removed and the pulp stored in plastic bags or earthenware pots. The dry ripe pods can easily be cracked and the pulp and fibers separated from the broken shells. The pulp is then processed by peeling and removing the fiber strands from the pulp. After separating the pulp from the fibers, the seeds, and shells, it is then compressed and packed in palm leaf mats, baskets, corn husks, jute bags, or plastic bags for storage and marketing. In most of the tamarind-growing countries, such as India and Africa, the pulp is pressed and preserved in large masses and sold in small shops and bazaars by weight. The quality and condition of the pulp and the selling price in the market are often related to the care taken during storage. In dry conditions the pulp remains good for about 1 year. Feungchan et al. (1996c) attempted several methods to prevent change of pulp color including powdered salt, steam, sun drying, hot air incubation, and cold storage.

13.22 Economics of Production

The cost involved in production is mostly with labor for field establishment, digging pits, weeding, and the purchase of seedlings or grafts. There is no income in first 3 years but intercropping with annual crops could compensate the labor and other costs. The orchards established through clones are of uniform size, the fruits are of high quality, and the trees yield well. Each tamarind will give an average yield of 100 kg of fresh tamarind pulp per year at maturity. The national and international commerce of tamarind is more limited for the following reasons:

- Tamarind has not received sufficient research attention over the years, and in most countries, unimproved trees are cultivated.
- Fresh fruits of the sour type have village level markets.
- Most of the fruits and seeds go to waste due to lack of technologies for processing and storage.
- Processed pulp is of low quality
- Alternate low cost processing technologies are not available.
- Products are restricted to domestic markets of producing countries.
- Most of the exports are from only a few of the major producing countries.
- Lack of both local and international market information restricts expansion of crop and product diversification.

13.23 Marketing

Tamarind is a delicacy in the producing countries and is used for various culinary purposes. It is consumed in fresh, dried, and other processed forms. The ripe pods are collected from trees grown in the wild or in home gardens; they are processed in households and sold in the village markets.

13.24 Export

International trade in tamarind has been in existence for a long time, though it is limited to the major producing countries. Only a small proportion of the total production is exported and this is mostly in the dried form. Tamarind is also exported as pulp, fresh fruit, paste, and industrial products including tamarind seed kernel powder. Demand for these products varies according to quantity and the country.

13.25 Post Harvest

13.25.1 Tamarind Juice Concentrate

It is a convenient product, as it is easy to dissolve and reconstitute in hot water (Anon 1982b). It can also be stored for long periods. It is prepared by extracting cleaned pulp with boiling water using the countercurrent principle, where dilute extracts are used for extracting fresh batches of the pulp.

13.25.2 Tamarind Pulp Powder

It is prepared by concentrating, drying, and milling the pulp into a powder form. Depending on the manufacturing process, wide variations in the physicochemical characteristic are reported. On a small scale, the fruit pulp is made into a refreshing drink after dissolving in water and squeezing by hand. The extraction and processing techniques of the pulp for the preparation of canned tamarind syrup, clarified tamarind juice, and other soft drinks have been reported by Bueso (1980).

13.25.3 Tamarind Pickle

Pulp is used commercially to prepare tamarind pickle. The pickles are commonly used in Asia. Pickles are hot, spicy, and of salty-sour taste and can be preserved for several months.

13.25.4 Jam

In making tamarind jam, ripe fruits are shelled and the pulp is boiled for 10 min. The pulp is then drained and separated from the seeds. For every cup of pulp, two cups of brown sugar are added. The mixture is then cooked and constantly stirred while boiling until it becomes thick in consistency. The resulting jam is cooled, packed in dry, sterilized jars, and sealed.

13.25.5 Syrup

Tamarind syrup is made by boiling immature fruit pulp until it is soft and then strained through cheesecloth. To every cup of juice, a half-teaspoon of baking soda is added. The mixture is boiled down to one half the original quantity, removing the rising scum in the process. The juice is again strained and for every cup obtained; a quarter cup of sugar is added. The mixture is boiled again for 20 min. The cooled syrup is poured in to sterilized bottles and sealed.

13.25.6 Candy

Sweetened tamarind fruit is made by peeling whole ripe fruits and pouring boiling sugar syrup over the fruits and placing in a deep enamel basin. Boiling syrup is prepared by mixing three parts of sugar with one part water. After soaking for 3 days, the fruits are drained of the old syrup and again covered with freshly prepared syrup. The process is repeated until the fruits are sweet enough.

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