Fruits for the Future 1
Revised edition

Tamarind

Tamarindus indica L.

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The World Agroforestry Centre (ICRAF), established in Nairobi in 1977, is an autonomous, non-profit research body supported by the Consultative Group on International Agricultural Research (CGIAR). ICRAF aims to improve human welfare by alleviating poverty, improving food and nutrition security and enhancing environmental resistance in the tropics.

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Preface

For the past six years the International Centre for Underutilised Crops has been disseminating information on production, utilisation, processing and marketing of a series of high priority underutilised tropical fruits. In this endeavour ICUC has been generously supported by the Department for International Development (DFID) of the UK. The project has been entitled 'Fruits for the Future'.

For each fruit a monograph has been issued as well as a manual aimed at the implementation of production at the farmer level.

The first monograph in a series was on tamarind authored by Prof. H.P.M. Gunasena of Sri Lanka and Miss A. Hughes of ICUC. The preparation of the monograph drew upon the expertise of a wide range of scientists in all parts of the world and resulted in a publication in 2000 which ICUC made available to all those with an interest in the culture and utilisation of tamarind.

The monograph was exceedingly well received judging from its recipients' responses and ICUC was continually asked for more information.

It soon became apparent that interest in this particular underutilised fruit species was accelerating and the research expanding. For these reasons it was agreed that a revised monograph should be issued as Fruits for the Future Monograph 1 to supersede the original.

We would like to thank all contributors of the revised edition and it is hoped that this current revised monograph will be even more useful for teachers, students, extensionists, policy makers, fruit tree growers and traders so that they may become instrumental in promoting the enhanced production, processing and marketing of tamarind.

Editors
2006

Chapter 1. Introduction, Taxonomy, Description and Distribution

J.T. Williams

1.1 Introduction

Tamarind, *Tamarindus indica* L., is a multipurpose tropical fruit tree used primarily for its fruits, which are eaten fresh or processed, used as a seasoning or spice, or the fruits and seeds are processed for non-food uses. The species has a wide geographical distribution in the subtropics and semi-arid tropics and is cultivated in numerous regions.

Tamarind belongs to the dicotyledonous family Leguminosae which is the third largest family of flowering plants with a total of 727 genera recognised and the number of species is estimated at 19,327 (Lewis *et al.*, 2005).

Tamarind is widely grown as a subsistence crop for meeting local demands. It is also grown commercially. Numerous national programmmes have recognised tamarind as an underutilised crop with wider potential since demand for products is substantial and the species can be incorporated into agroforestry systems. There are also well established international trade channels. Further exploitation of tamarind can therefore provide added incomes for poor rural people thereby improving their well-being.

1.2 Taxonomy

1.2.1 *Tamarindus* in the Leguminosae

Tamarindus belongs to the subfamily Caesalpinioideae which in turn has been variously divided into a number of tribes. Opinions are still divided on how many tribes there are, or indeed to which one *Tamarindus* belongs. Léonard (1957) included it in the Amherstieae (Pettigrew and Watson, 1977) which contains 25 genera. More recently it was included in the tribe Deterieae thought to be close to Amherstieae. The genus *Heterosteman* was thought to have some resemblance to *Tamarindus* (Dassanayake, 1999, pers. comm.) as do *Amherstia* and *Brownea*.

Differences of opinion probably stemmed from the fact that morphological trends can occur independently in different groups of the Deterieae as suggested by Polhill and Raven (1981), this fact alone causing them to think that Amherstieae was not monophyletic.

Lewis *et al.* (2005) have summarised the latest morphological and molecular analyses and continued work will clarify the exact positioning of *Tamarindus* in relation to its putatively related genera.

Tamarindus itself is a monotypic genus, containing the sole species *T. indicus*.

1.3 Nomenclature

Tamarindus indicus L. Species Plantarum (1753) 34

It is thought that Linnaeus gave the specific epithet *indicus* because the name tamarind itself was derived from Arabic which combined Tamar meaning 'date' with Hindi meaning 'of India'. The full Arabic name was Tamar-u'l-Hind and the word date included because of the brown appearance of tamarind pulp.

Subsequent botanists differentiated between tamarind from the West Indies (*T. occidentalis* Gaertn.) and tamarind from the East Indies (*T. officinalis* Hook.). Jackson (1895) in *Index Kewensis*, found these names to be superfluous and the descriptions insufficient to separate the two species.

1.3.1 Vernacular names

The local names used in various regions and languages are shown in Table 1.1.

Table 1.1 Common/vernacular names of tamarind

Country	Language	Name(s)
Africa		
	Bemba	mushishi
	Fula	dabe, jammeth, jammi
	Jola	budahar
	Mandinka	timbimb, timbingo, tombi, tomi
	Tigrina	humer
	Wolof	daharg, dakah, dakhar, nclakhar
Ethiopia	Amharic	hemor, homor, humar, komar, tommar
	Tigrina	arabeb
	Gamo/Oromo	b/roka, racahu, dereho, dindie, ghroma, gianko, omar
Kenya	Swahili	mkwaju
	Masai	ol-masamburai
	Turkana	eopduran
	Borana	roka

Country	Language	Name(s)
	Luo	chwa. waa
	Meru	muthithi
	Pökot	oran
Malawi	Chewa	ukwaju, bwemba
	Yao	mkwesu
	Nkande	nkewesu
Nigeria		tsamiya
Somalia	Somali	hamar
South Africa	Afrikaans	tamarinde
Sudan	Arabic	aradeib, tamarihindi
	Nuba	shekere, kuashi, danufi
Tanzania	Swahili	ukwaju
Uganda	Teso	esukuru, esuguguru (leaves)
	Teso/Karamojong	e/apedura (fruit)
	Bari/Ma'di	iti
	Acholi/Lango	chwa/o
	Kakwa/Acholi	pitei
	Luganda	mukoge
Zambia	Bemba	mushishi
	Nyanja	mwemba
	Tonga	musika
Asia		
Cambodia	Khmer	'am' pul, ampil, khoua me
China	Sino-Tibetan	khaam, mak kham
India	Hindi	ambli, amli, imli
	Sanskrit	amalika
	Bengali	tintiri, tintul, tetul
	Marathi	chinch, chitz, amli
(Hyderabad)		chis, hunchi
(Mysore)		karanji, kamal, asam, hunse
	Kannada	hunase, unsi, hulimara
	Coorg	pulinje
	Uriya	koya, tentuli
	Gondi	chita, hitta, sitta

Country	Language	Name(s)
	Telegu	chinta
	Tamil	puli, pulian
	Assamese	tetili
	Gujarati	amali, ambali
Indonesia		asam jawa, assam, tambaring
Malaysia		asam jawa
Myanmar		magyi, magyee majee-pen
Nepal	Nepali	ttri, imli
	Newari	titis, paun
Philippines	Tagalog	sampalok
	Bisaya	kalamagi
	Ilokano	salomagi
Sri Lanka	Sinhala	siyambala, maha siyambala
	Tamil	puli
Thailand	general	makham
	northern	bakham
	peninsular	somkham
Vietnam		me, trai me
Elsewhere		
Virgin Islands		tanan
	Arabic	ardeib
	Creole	tamarenn
	Dutch	tamarinde
	English	Madeira mahogany, tamarind, Indian date
	French	tamarin, tamarainer, tamarindier
	German	tamarinde
	Italian	tamarindizio
	Portuguese	tamarindo
	Spanish	tamarin, tamarindo

Source: Coronel (1991); Salim *et al.* (1998)
http://www.worldagroforestry.org/Sites/TreeDBS/aft/speciesPrinterFriendly.asp?Id=1589

1.4 Description

1.4.1 Vegetative morphology

Tamarind is a long-lived, large, evergreen or semi-evergreen tree, 20-30 m tall with a thick trunk up to 1.5-2 m across and up to 8 m in circumference. The trunk forks at about 1 m above ground and is often multi-stemmed with branches widely spreading, drooping at the ends and often crooked but forming a spreading, rounded crown. The bark is brownish-grey, rough and scaly. Young twigs are slender and puberulent. A dark red gum exudes from the trunk and branches when they are damaged.

Root
Tamarind produces a deep tap root and an extensive lateral root system, but the tap root may be stunted in badly drained or compacted soils. The tap root is flexuous and lateral roots are produced from the main root at different levels.

Leaves
Leaves are alternate and even pinnate, in length (5-)7-12(-15) cm, shortly petiolated (up to 1.5 cm long) and petiole glabrous or puberulent as is the leaf rachis (Fig. 1.1). Laminae are glabrous or puberulent, glaucous underneath and darker green above. Venation is reticulate and the midrib of each leaflet is conspicuous above and below. Leaflets are in (6-)10-18(-20) pairs / leaf, each narrowly oblong, rounded at the apex and slightly notched and asymmetric with a tuft of yellow hairs; at the base obliquely obtuse or subtruncate. At the leaf base is a pulvinus and two small stipules 0.5-1.0 cm long which are caducous early on; stipules are falcate, acuminate and pubescent. A permanent scar is seen after leaf fall.

Leaflets fold after dark due to the presence of lupeol synthesised when light and degraded in the dark (Ali *et al.*, 1998).

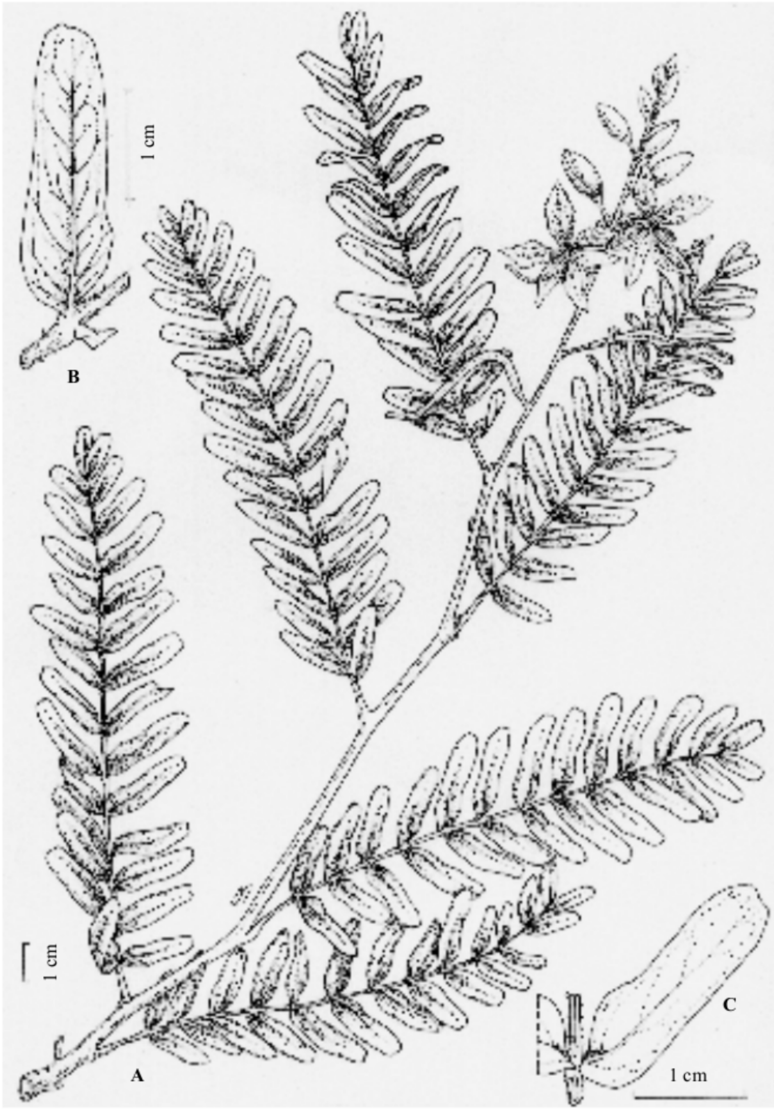

Figure 1.1 Compound leaves and leaflets of tamarind

A - Branch/ twig showing habit, arrangement of compound/ pinnate leaves on stem and terminal inflorescence containing two immature fruits. **B** - Detail of under surface of leaflet to show venation. **C** - Detail of upper surface of leaflet to show groove in leaf/rachis (Illustrations by Ms N. Simpson).

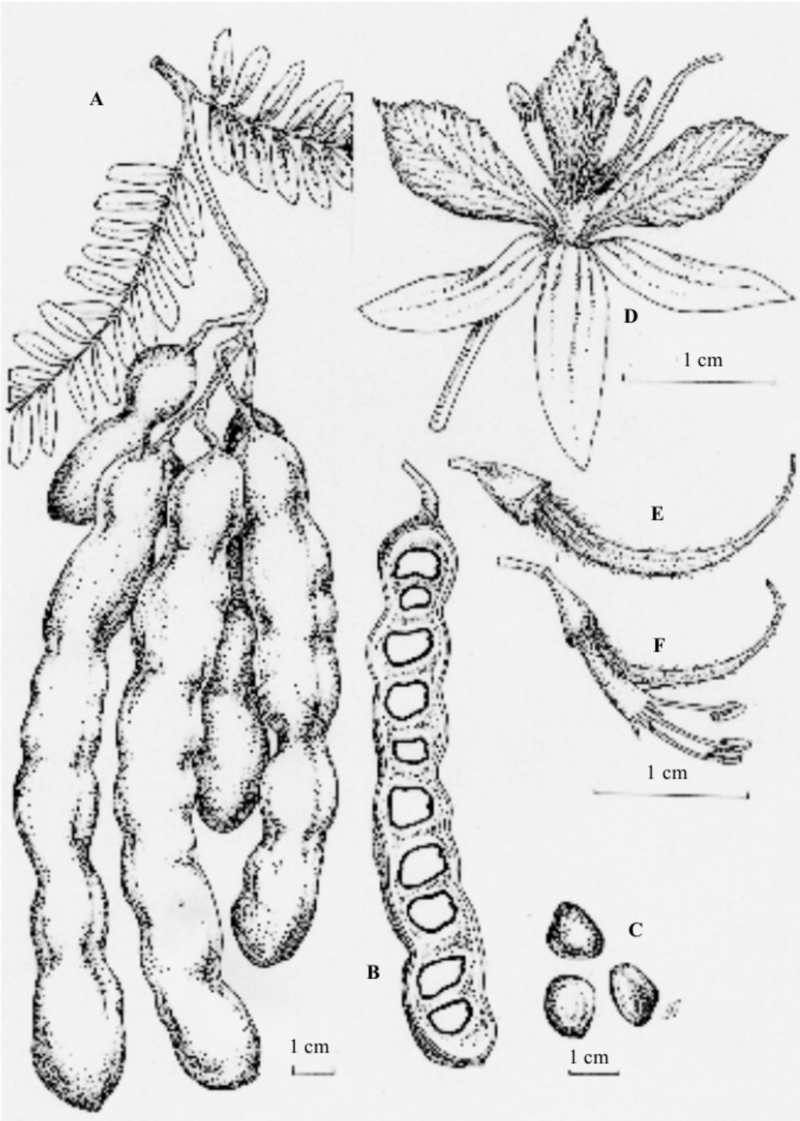

Figure 1.2 Flower and pods of tamarind showing the pistil, stamens and seed

A - Cluster of mature fruits. **B** - Vertical section through a single pod/ fruit to show seed arrangement. **C** - 3 seeds. **D** - Flower. **E** -Detail of pistil and stigma. **F** - Detail of corolla tube, pistil and stamens (Illustrations by Ms N. Simpson).

1.4.2 Flowers

Flowers are borne in lax racemes which are few to several flowered (up to 18), borne at the ends of branches and are shorter than the leaves, the lateral flowers are drooping (Fig. 1.2. See Plate 1).

Flowers are irregular 1.5 cm long and 2-2.5 cm in diameter each with a pedicel about (5-)6(-10) mm long, nodose and jointed at the apex. Bracts are ovate-oblong, and early caducous, each bract almost as long as the flower bud. There are 2 bracteoles, boat shaped, 8 mm long and reddish.

The calyx is (8-)10(-15) mm long with a narrow tube (turbinate) and 4 sepals, unequal, ovate, imbricate, membranous and coloured cream, pale yellow or pink.

Corolla of 5 petals, the 2 anterior reduced to bristles hidden at the base of the staminal tube. The 3 upper ones are a little longer than the sepals, 1 posterior and 2 lateral, these 3 obovate to oblong, imbricate, coloured pale yellow, cream, pink or white, streaked with red.

Flowers are bisexual. The colour of the flowers is the same on each tree; they are not mixed. Stamens are 3(-5) fertile and 4 minute sterile ones. Filaments of fertile stamens are connate and alternate with 6 brittle-like staminodes. Stamens are united below into a sheath open on the upper side and inserted on the anterior part of the mouth of the calyx tube. Anthers are transverse, reddish brown and dehisce longitudinally.

The ovary is superior with few to many (up to 18) ovules. The ovary is borne on a sheath adnate to the posterior part of the calyx tube. It is stipitate, curving upwards and is green with a long hooked style with a terminal subcapitate stigma.

Flowers are protogynous, entomophilous and largely cross-pollinated. Flowers are nectiferous, nectar being produced by hairs at the ovary base (Thimaraju *et al.,* 1977; Tucker; 2000). Some self-pollination also occurs (Coronel 1991).

1.4.3 Fruits and seeds

The fruits are pods 5-10(-16) cm long x 2 cm broad, oblong, curved or straight, with rounded ends, somewhat compressed and indehiscent although brittle (Fig. 1.2). The pod has an outer epicarp which is light grey or brown and scaly. Within is the firm but soft pulp which is thick and blackish brown. The pulp is traversed by formed seed cavities, which contain the seeds. The outer surface of the pulp has three tough branched fibres from the base to the apex (see Plate 2).

Each pod contains 1-12 seeds which are flattened, glossy, orbicular to rhomboid, each 3-10 x 1.3 cm and the centre of each flat side of the seed marked with a large central depression. Seeds are hard, red to purple brown, non arillate and exalbuminous. Seed chambers are lined with a parchment-like membrane. Cotyledons are thick.

Seed size is very variable and there are (320-)700(-1000) per kilo (von Carlowitz, 1986; Hong *et al.,* 1996; El-Siddig *et al.,* 2000).

Pods ripen about 10 months after flowering and can remain on the tree until the next flowering period, unless harvested (Rana Rao, 1975; Chaturvedi, 1985).

1.5 Origin

Various geographical areas have been proposed for the origin of tamarind: India (Morton, 1987) or the Far East or Africa (Coates-Palgrave, 1988) but the consensus is that it is Africa. Troup (1921) placed it in Ethiopia, but others considered it indigenous to the drier savannahs of tropical Africa, from Sudan, Ethiopia, Kenya and Tanzania, westward through sub-Sahelian Africa to Senegal (Brandis, 1921; Ridley, 1922; Dalziel, 1937; Dale and Greenway, 1961; Irvine, 1961; NAS, 1979). Figure 1.3 shows the indigenous distribution. Around homesteads in Africa it is still wild or protected.

Figure 1.3 The shaded area represents the approximate indigenous range of tamarind in Africa

It is thought to have been introduced to South and Southeast Asia a very long time ago (Brenan, 1967; NAS, 1979) and it naturalised in many areas where it was introduced (Simmonds, 1984; Purseglove, 1987; Coronel, 1991).

1.6 Geographical Distribution

The geographical distribution of tamarind has been documented by Salim *et al.* (1998) as follows:

Native: Burkina Faso, Cameroon, Central African Republic, Chad, Ethiopia, Gambia, Guinea, Guinea-Bissau, Kenya, Madagascar, Mali, Niger, Nigeria, Senegal, Sudan, Tanzania, Uganda, Cape Verde.

Exotic: Afghanistan, Australia, Bangladesh, Brazil, Brunei, Cambodia, China, Colombia, Côte d' Ivoire, Cuba, Dominican Republic, Egypt, Ghana, Greater and Lesser Antilles, Haiti, Hawaii, Honduras, India, Indonesia, Iran, Jamaica, Laos, Liberia, Malaysia, Mauritania, Mexico, Myanmar, Nicaragua, Pakistan, Papua New Guinea, Philippines, Puerto Rico, Sri Lanka, Thailand, Trinidad, Tobago, Togo, United States of America, Vietnam, Zambia.

1.6.1 Africa

Tamarind occurs widely throughout tropical Africa, where it is frequently planted as a shade tree (Storrs, 1995). It is commonly found in woodlands, and is well adapted to the arid and semi-arid zones (Watt, 1893; Purseglove, 1987; Coronel, 1991; Albrecht, 1993, quoted by Hong *et al*., 1996). It is well known in Senegal whose capital city Dakar is named after the tree. The local name is 'dakhar' (NAS, 1979). In Kenya, tamarind is naturalised and cultivated in the coastal districts and is considered to be equal in importance in the local markets to cashew and mango. It is an attractive shade and ornamental tree and forms a meeting place for people in the villages (Vogt, 1995). Tamarind is also found on the island of Zanzibar where it occurs on homestead plantations. The tree grows abundantly in Madagascar and can be found in various localities such as Kilelo, Kily, Madiro, Voamatory and Medilo. As noted by Cabanis *et al*. (1969) many botanists believed that the species was introduced to Madagascar, however, Perrier de la Bâthie (1936) considered it to be native and from here spread to Asia (Von Mueller, 1881; Von Maydell, 1986).

1.6.2 Asia

Tamarind is now widely spread throughout semi-arid South and Southeast Asia (Gamble, 1922; Chaturvedi, 1985). It is presently cultivated in home gardens, farmlands, on roadsides, on common lands and on a limited plantation scale in India and Thailand, where the species is more economically important. In India, it is most commonly grown in the drier warmer areas of the South and Central region, where it thrives best, although it is planted as far North as Punjab, where the fruits do not ripen (NAS, 1979; Sozolnoki, 1985 and Coates-Palgrave, 1988). Sometimes tamarind groves are seen in India, these are thought to mark deserted villages.

The tree is believed to have been introduced to Sri Lanka in pre-historic times (Watanabe and Dissanayake, 1999). It grows in the dry and intermediate zones, up to an elevation of about 600 m through natural regeneration or sometimes as a planted tree (Gunasena, 1999). It is very conspicuous in the dry regions, every village having several, often magnificent specimens. The trees are occasionally found apparently wild in the jungle, but always on the sites of abandoned villages (Trimen, 1894). Tamarind is often used as a roadside or avenue tree grown along canals, particularly in the North and South dry zones (Macmillan, 1943). Similarly, in the Philippines, tamarind is grown extensively as a backyard tree. Again the time of introduction is unknown (Merril, 1912; Webster and Barrett, 1912; Villanueva, 1920; Webster, 1920, 1921; Brown, 1954). In Thailand, the tree grows from sea level up to 2000 m and products are collected mostly from wild trees, although a few small scale sweet tamarind orchards have been established recently (Feungchan *et al.,* 1996 a).

Tamarind is not commonly seen throughout Malaysia, except in the north where the ecological conditions are better suited. It is not used for avenue planting as in India, but occurs in towns and villages, chiefly in the neighbourhoods of Indian dwellings (Corner, 1945). It is mainly cultivated in the North at Penang and in the province of Wellesley. It has occurred as an escape in Singapore on a rocky island in the Johor Strait and in Selangor and Kedah (Ridley, 1922). Tamarind is commonly grown in the villages of Myanmar, in dry areas where the rainfall varies from 230-400 mm, but is not found in the wild state (Troup, 1921). Tamarind is also well established in the dry areas of Fiji. It is believed to have been introduced by Indian labourers for culinary purposes, but it is presently grown as a shade tree and restricted to elevations below 230 m (Parham, 1972; Jayaweera, 1981).

1.6.3 The Americas

Patino (1969) states that the first reference to tamarind in the Americas is from Acapulco (Mexico) in 1615, suggesting that it may have arrived from Asia across the Pacific with the Spanish. Tamarind is now produced commercially in Mexico and is widespread in the states of Chiapas, Colima, Guerro, Jalisco, Oaxaca and Veracruz, covering an area of 4440 ha (10,000 acres). From Mexico, tamarind was probably introduced throughout tropical America and the Caribbean Islands. The dates of introduction are unknown, however it is thought to have occurred in Hawaii in 1797 where it persists today in small numbers across the islands (Morton, 1987). Tamarind is also found growing throughout the Caribbean islands including Jamaica, Cuba, the Greater and Lesser Antilles and the Dominican Republic. It is common along roadsides, around houses, on hillsides and in dry coastal regions (Little and Wadsworth, 1964). In Puerto Rico tamarind is grown commercially, annual production being ca. 23 tons (Bueso, 1980). There are also commercial plantations in Brazil and other Latin American countries, but few trees regenerate naturally. It does regenerate in Guatemala where the Montague valley is known as El Tamarindal, and in the Keys of Florida.

The areas where tamarind has been introduced are shown in Fig. 1.4.

Figure 1.4 Native and naturalised distribution of tamarind

1.7 Historical information

The movement of tamarind to Asia must have taken place in the first millenium BC. Cultivation of tamarind in Egypt by 400BC has been documented and it was mentioned in the Indian Brahmasamhita Scriptures between 1200-200 BC. About 370-287 BC Theophrastus wrote on plants and two descriptions refer to tamarind, even though not named as such (Hort, 1916); his sources were probably from East Africa.

Trade between the Mediterranean and the Orient was common in the centuries towards the end of the first millenium BC when spices were imported. These trade routes also linked southwards to East Africa. Although most information relates to plants brought westwards, some must have been carried the other way. By 1000 AD the Arabs dominated this trade and Marco Polo recorded that Arab traders made tamarind an important commercial item in Medieval Europe.

Chapter 2. Properties of the Species

Revised by J.T. Williams

2.1 Introduction

Tamarind is a nutritious fruit with a variety of uses. The properties of this species have been extensively studied, particularly with reference to the components of the seed. Tamarind has many valuable properties and virtually every part of the tree has been utilised by both rural and urban dwellers. All parts are used in traditional medicine; data relating to such uses are included in Chapter 3.

2.2 Pulp

The most valuable and commonly used part of the tamarind tree is the fruit. The pulp constitutes 30-50% of the ripe fruit (Purseglove, 1987; Shankaracharya, 1998), the shell and fibre account for 11-30% and the seed about 25-40% (Chapman, 1984; Shankaracharya, 1998). The large range is associated with heterozygosity since many cultivated forms have been seed propagated (Benero *et al.*, 1974).

Table 2.1 Mean composition of tamarind fruit

Constituents	Amount (per 100 gm)
Water	17.8-35.8 g
Protein	2-3 g
Fat	0.6 g
Carbohydrates	41.1-61.4 g
Fibre	2.9 g
Ash	2.6-3.9 g
Calcium	34-94 mg
Phosphorous	34-78 mg
Iron	0.2-0.9 mg
Thiamine	0.33 mg
Riboflavin	0.1 mg
Niacin	1.0g
Vitamin C	44 mg

Source: Coronel (1991); Feungchan *et al.*, (1996 a).

Fruit composition also depends on locality (Table 2.2). Tamarind has a low water content and a high level of protein, carbohydrates (60-72%) and minerals. The soluble solids content varies from 54-69.9° Brix (Benero *et al.*, 1974; Baragano de Mosqueda, 1980). Ishola *et al.* (1990) have reported that the pulp of a Nigerian provenance was poor in proteins (87.9 g/kg) and oil (25.3 g/kg). Soloviev *et al.* (2004) looked at fruit composition, especially in relation to total stable sugars, total free acidity and water content in a range of genotypes in Senegal. Such chemical characters varied widely but less than biometrical ones related to morphological characterisation. Such studies are helpful in selecting suitable genotypes for enhanced domestication.

Table 2.2 Proximate composition and food energy value of ripe tamarind pulp (%) from five different areas

Constituents	a	b	c	d	e
Water	20.60	15.00-47.00	22.60	33.89	62.50-69.20
Protein	3.10	14.00-3.40	3.10	3.28	1.40-3.30
Lipids			0.40	0.50	0.71-0.81
Fat	0.40	0.90-1.00	0.40	0.50	0.71-0.81
Carbohydrate (30-40% reducing sugars)	70.80	62.50	71.80	59.76	
Total Sugars					21.40-30.85
Fibre	3.00	5.10	3.00	1.79	
Cellulose					1.80-3.20
Pentose					4.20-4.80
Total acidity					17.10-18.40
Free tartaric acid					8.40-12.40
Ash	2.10	1.50-4.20	2.10	2.57	1.16-1.72
Energy (kcal/100g)			272.0	230.0	
Calcium		0.07			
Phosphorus		0.11			

Source: (a) Purseglove (1987); (b) FAO (1988); (c) Leung and Flores (1961); (d) Wenkam and Miller (1965); (e) Hasan and Ijaz (1972).

The pulp contains oil, which is greenish in colour and liquid at room temperature. The saponification value of the oil is high but the iodine value is low. Some physico-chemical properties of the pulp and seed are shown in Table 2.3.

Table 2.3 Some physico-chemical properties of the lipid extracted from the pulp and seed of tamarind

	Pulp	Seed
Saponification value (mg KOH g^{-1})	301.3	266.6
Iodine value	120.6	78.1
Unsaponified matter (g kg^{-1})	139.0	31.3
Acid value (g kg^{-1})	896.0	292.6
Free fatty acid (g kg^{-1})	448.0	46.3
Peroxidase value (m Eq kg^{-1})	123.3	98.9

Source: Ishola *et al.* (1990)

The major volatile constituents of tamarind pulp include furan derivatives (44.4%) and carboxylic acids (38.2%), the components of which are furfural (38.2%), palmitic acid (14.8%), oleic acid (8.1%) and phenylacetaldehyde (7.5%) (Wong *et al.,* 1998). According to Lee *et al.* (1975), the most abundant volatile constituent of tamarind is 2-acetyl-furan, coupled with traces of furfural and 5-methylfurfural, which form the total aroma of tamarind. The total content of volatile compounds in fruit pulps can be around 3 mg/kg. Apart from the major volatile components listed above there may be up to 81 different volatile substances (Pino *et al.*, 2004).

The fruit contains a variety of pigments. The red colour is due to water-soluble red-rose anthocyanin pigment, while in the common types of pulp leuco-cyanidin is present (Lewis and Neelakantan, 1964 a; Bhattacharyya, 1974).

Lectins have been shown to be present and these could be of medical interest (Coutino-Rodriguez *et al.,* 2001). Triterpenoids are also a constituent (Neetu and Bohra, 2003).

The most outstanding characteristic of tamarind is its sweet acidic taste, the acid due mostly to tartaric acid (2,3-dihydroxybutanedioic acid, $C_4 H_6 O_6$, a dihydroxydicarboxylic acid), ranging from 12.2-23.8%, and uncommon in other plant tissues (Ulrich, 1970). It is an unusual plant acid, which is formed from the primary carbohydrate products of photosynthesis, and once formed, it cannot be further used in the plant due to the absence of the necessary enzymes. Although tartaric acid occurs in other sour fruits, such as grapes, grapefruit and raspberries, it is not present in such high proportions as in tamarind. The tartaric acid is synthesised in tamarind leaves in the light and translocated to the flowers and fruits (Lewis *et al.*, 1961; Patnaik, 1974). It is high in young leaves and decreases with age and has been reported to show seasonal variations (Bueso, 1980). As reported by Lewis and Neelakantan (1964 b) the tartaric acid content in leaves decreased from 28-12% suggesting that this is due to its transfer to the fruit during ripening. The content of tartaric acid, however, does not decrease during fruit ripening, indicating that it is not utilised in fruit development; but during this time, reducing sugars increase to 30-40% giving the sour fruit a sweeter taste. As the acidity does not disappear with ripening, but is more or less matched with increasing sugar levels, tamarind is known to be simultaneously the most acidic and sweetest fruit (Lewis and Neelakantan, 1964 a; Coronel, 1991).

In general, the dried tamarind pulp of commerce contains 8-18% tartaric acid and 25-45% reducing sugars of which 70% is glucose and 30% fructose (Table 2.4). Lewis and Neelakantan (1964 a) reported that one half of the tartaric acid was present as potassium bitartarate (*cream of tartar*) and to a lesser extent as calcium tartarate. The tender fruits contain most of the tartaric acid in free form (up to 16%), which can be easily extracted with hot water. Lewis *et al.* (1961) also reported that tartaric acid is present at all stages of fruit development as an optically active (+) isomer. The most commonly found isomer in fruit is malic acid; about 1.37 mg/l existed as the (-) form in tamarind fruits.

The ascorbic acid content in tamarind is very small and varies from 2-20 mg/100g (Lefevre, 1971; Ishola *et al*., 1990). The other organic acids reported in tamarind fruit are oxalic acid, succinic acid, citric acid and quinic acid (Lewis and Neelakantan, 1964 a; Singh, 1973; Anon, 1976). The tamarind pulp does not contain any detectable amounts of phytic acid, but the trypsin activity is higher than in the seed (Ishola *et al*., 1990).

Genotypes have been selected which have particularly sour or particularly sweet tastes. Hence it is not surprising that different authors have reported wide variations in the tartaric acid and sugar contents of tamarind pulp. In Pakistan, Hasan and Ijaz (1972) found that in sour tamarind the tartaric acid content varied from 8.4-12.4% and the sugar from 21.4-30.9%. In Thailand, the tartaric acid content varied from 2.5-11.3% and the sugar from 5.0-40.0%. According to Feungchan *et al.* (1966 e), the tartaric acid content of sweet tamarind in Thailand was as low as 2.0-3.2% and the sugar was as high as 39.1-47.7%. The sugar content of the sweet tamarind types in Thailand (Table 2.5) varies between 39.06-47.71%, whereas the sugar content of sour tamarind is 4.80-38.94%. The sweet and sour types have been reported to contain 6.6-9.8% tartaric acid (free), 6.7-11.4% tartaric acid (combined), 36.4-38.2% invert sugars and 2.4-4.4% pectin (Anon, 1976).

Table 2.4 Proximate composition of dried pulp of tamarind fruit per 100 g dry weight

Constituent	Percentage
Moisture	15.00-30.00
Proteins	2.00-9.10
Fat/oil/lipid, crude	0.50-3.10
Carbohydrates, total	56.70-82.60
Fibre, crude	2.20-18.30
Tartaric acid, total	8.00-18.00
Reducing sugars	25.00-45.00
Total ash	2.10-3.30
Pectin	2.00-4.00
Cellutosic residue	19.40
Albuminoids	3.00-4.00
Total available carbohydrates	41.77
Alcohol insoluble sugars	22.70
Water insoluble sugars	20.50
Non-reducing sugars	16.52
Total sugars	41.20-58.7
Starch	5.70
Tannin, (mg)	600.00
Ascorbic acid, (mg)	3.00-9.00
β-carotene equivalent (μg)	10.00-60.00
Thiamine (mg)	0.18-0.22
Roboflavin (mg)	0.07-0.09
Niacin (mg)	0.60

Source: Meillon (1974); Anon (1976); Duke (1981); Ishola *et al*. (1990); Parvez *et al.* (2003)

Table 2.5 Chemical composition of sweet tamarind pulp from Thailand

Cultivar	Tartaric Acid (%)	Sugar (%)	Acid/Sugar Ratio	Fibre (%)
Sithong	3.18	41.07	1 : 13	1.44
Piyai	2.01	47.19	1 : 23	1.97
Praroj	2.70	43.09	1 : 16	0.88
Srichompoo	2.39	42.52	1 : 18	1.96
Kru-in	2.70	39.06	1 : 14	1.02
Jaehom	44.68	47.71	1 : 16	1.33
Pannanikom	2.34	47.71	1 : 20	1.10

Source: Feungchan *et al*. (1996 e).

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% is free amino acids. The following free amino acids were identified in the tamarind pulp: proline, serine, beta-alanine, phenylalanine and leucine. These amino acids were present in higher quantities in the ripe fruits than in immature fruits, indicating the accumulation of free amino acids during the maturation and ripening of tamarind.

Tamarind pulp is also rich in minerals: high in potassium (62-570 mg/100g); phosphorus (86-190 mg/100 g); and calcium (81-466 mg/100g), and a fair source of iron (1.3-10.9 mg/100g). The content of magnesium (25.6-30.2 mg/100g) is high, as is sodium (23.8-28.9 mg/100g) but low for copper (0.8-1.2 mg/100g) and zinc (0.8-0.9 mg/100g) according to Parvez *et al.* (2003). It also excels in riboflavin and is a good source of thiamin and niacin, but is poor in vitamin A and vitamin C (Leung and Flores, 1961) (see Table 2.10).

Tamarind fruit contains a biologically important source of mineral elements and with a high antioxidant capacity associated with high phenolic content can be considered beneficial to human health. The phenolics include gallic acid equivalent of 626-664 mg per 100g (Parvez *et al.*, 2003; see also Soong and Barlow, 2004 and Komutarin *et al.*, 2004).

2.3 Seeds

The seed comprises the seed coat or testa (20-30%) and the kernel or endosperm (70-75%) (Coronel, 1991; Shankaracharya, 1998). Tamarind seed is the raw material used in the manufacture of tamarind seed kernel powder (TKP), polysaccharide (jellose), adhesive and tannin. The seeds are also used for other purposes and are presently gaining importance as an alternative source of protein, rich in some essential amino acids. Unlike the pulp the seed is a good source of protein and oil. There has been considerable interest amongst chemists, food technologists and nutritionists in the study of the properties of tamarind seeds e.g. recent work on stabilisation of xyloglucans of the tamarind seed polysaccharide (Picout *et al.*, 2003) and the gelling behaviour of polyose from tamarind kernel powder so that pectin/polyose mixes can be recommended (Marathe *et al.*, 2002).

Whole tamarind seed and kernels are rich in protein (13-20%), and the seed coat is rich in fibre (20%) and tannins (20%) (Table 2.6). Panigrahi *et al.* (1989) reported that whole tamarind seed contains 131.3 g/kg crude protein, 67.1g/kg crude fibre, 48.2 g/kg crude fat, 56.2 g/kg tannins and trypsin inhibitor activity (TIA) of 10.8, with most of the carbohydrate in the form of sugars. The trypsin inhibitor activity is higher in the pulp than in the seed, but both are heat labile. According to Ishola *et al.* (1990), the seed also contains 47 mg/100g of phytic acid, which has minimal effect on its nutritive value. It also contains 14-18% albuminoid tannins located in the testa. According to Purseglove (1987), the seeds contain 63% starch and 4.5-6.5% of semi drying oil. Both pulp and the seeds are good sources of protein (269.3 g/kg), oil (109.1 g/kg) and calcium (Ishola *et al.,* 1990).

Table 2.6 Composition of tamarind seed, kernel and testa (%)

Constituent	Whole seed	Seed kernel (cotyledons)	Testa (seed coat)
Moisture	9.4-11.3	11.4-22.7	11.0
Protein	13.3-26.9	15.0-20.9	
Fat/oil	4.5-16.2	3.9-16.2	
Crude fibre	7.4-8.8	2.5-8.2	21.6
Carbohydrates	50.0-57.0	65.1-72.2	
Total Ash	1.60-4.2	2.4-4.2	7.4
Nitrogen-free extract	59.0		
Yield of TKP	50.0-60.0		
Calories/100g	340.3		
Total sugar	11.3-25.3		
Reducing sugars	7.4		
Starch	33.1		
Tannin			20.2

Source: Anon (1976), Morad *et al*. (1978); Ishola *et al*. (1990); Bhattacharyya *et al*. (1994)

Tamarind seeds are reported as a source of food or food ingredients due to the presence of proteins (Marangoni *et al.*, 1988). The crude protein and nitrogen free extracts comprise 15.5% and 59% of the seed, respectively. Pentose sugars constitute approximately 20% of the soluble sugars. Mannose (17-35%) and glucose (11.80%) were the principal soluble sugars.

Alkali extraction of the seeds showed that about 70% of the proteins were extractable. The protein isolated was relatively high in lysine (406 mg/g N), phenylalanine, tyrosine (520 mg/g N) and leucine (496 mg/g N) (Marangoni *et al.,* 1988). The seeds are an important source of proteins and valuable amino acids (Shankaracharya, 1998). Albumins and globulins constitute the bulk of the seed proteins.

The seed is rich in cystine and methionine but threonine and tryptophan are limiting (Table 2.7). Tamarind has a very good balance of essential amino acids. Except for the limiting amino acids, threonine and tryptophan the value of other amino acids is as high or higher than the FAO reference protein (FAO, 1970). The content of sulphur amino acids, 3.5% is equally divided between methionine and cystine, and is unusually high for legumes, while its high lysine content is similar to that of many food legumes, such as soybean, chickpea, groundnut and cowpea (FAO, 1970; de Lumen *et al.*, 1986, 1990). Tamarind seed protein has a very favourable amino acid balance; hence it could be used not only to complement cereals but also to supplement legumes with lower methionine and cystine contents. Since production is high in tamarind and as the seed constitutes over 40% of the pod, a high protein yield can be harvested from the seeds.

Table 2.7 Amino acid content of tamarind and some food legumes, mg/g N (Total N)

Amino acid	Tamarind	Ground nut	Cowpea	Chickpea	Soybean
Isoleucine	313	211	239	277	284
Leucine	531	400	440	468	486
Lycine	475	221	427	428	399
Methionine	113	72	73	65	79
Cystine	106	78	68	74	83
Phenylalanin	318	311	323	358	309
Tyrosine	287	244	163	183	196
Threonine	200	163	225	235	241
Tryptophan		65	68		80
Valine	306	261	283	284	300
Arginine	450	697	400	588	452
Histidine	143	148	204	165	158
Alanine	312	243	257	271	266
Aspartic	768	712	689	725	731
Glutamic	1056	1141	1027	991	1169
Glycine	331	349	234	251	261
Proline	287	272	244	263	343
Serine	350	299	268	318	320

Source: FAO (1970); de Lumen *et al*. (1986, 1990).

Seed Kernel Oil: The seed oil is a golden yellow, semi-drying 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. The major fatty acids were palmitic, oleic, linoleic, and eicosanoic. The lipids contained a relatively large proportion of unsaturated fatty acids, with linoleic acid (36-49%) in the highest concentration. Other major fatty acids are oleic acid (15-27%) and palmitic acid (14-20%) (Singh, 1973).

Sterols, beta-amyrin, campesterol and beta-sitosterol have been identified in the unsaponifiable matter of the seeds (Table 2.8). As in the pulp, the saponification value is high, because it contains low molecular weight fatty acids. The iodine value of seed lipids is much lower than in pulp lipids suggesting lower unsaturation and probably higher stability of seed oil (see Table 2.3).

Table 2.8 Fatty acid composition of tamarind seed oil

Fatty acids	Percentage
Palmitic	14-20
Stearic	6-7
Oleic	15-27
Linoleic	36-49
Arachidic	2-4
Behenic	3-5
Lignoceric	3-8
Sterols	
% of total sterols:	
Beta sitosterol	66-72
Campesterol	16-19
Stigmasterol	11-14

Source: Andriamanantena *et al*. (1983).

The seed kernel is rich in phosphorus (68.4-165 mg / 100g), potassium (273-610 mg / 100 g) and magnesium (17-118 mg / 100 g) (Table 2.9). The macronutrients, calcium, magnesium, potassium and phosphorus, however, were low in comparison with other cultivated legumes (Bhattacharya *et al.*, 1994).

Table 2.9 Mineral content of tamarind pulp, seed, kernel and testa

Mineral mg/100g	**Pulp**	**Seed**	**Kernel**	**Testa**
Calcium	81.0-466.0	9.3-786.0	120.0	100.0
Phosphorus	86.0-190.0	68.4-165.0		
Magnesium	25.0-72.0	17.5-118.3	180.0	120.0
Potassium	62.0-570.0	272.8-610.0	1020.0	240.0
Sodium	3.0-76.7	19.2-28.8	210.0	240.0
Copper	0.8-1.2	1.6-19.0		
Iron	1.3-10.9	6.5	80.0	80.0
Zinc	0.8-1.1	2.8	100.0	120.0
Nickel	0.5			
Manganese		0.9		

Source: Marangoni *et al.* (1988); Ishola *et al*. (1990); Bhattacharya *et al.* (1994); Parvez *et al.* (2003).

2.4 Leaves and Flowers

The leaves are used as a vegetable by indigenous 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. Leaves contain tartaric acid and maleic acid; the latter is found in excess and increases with the age of the leaves. Oxalic acid (196 mg/100g) is also present and the tender leaves show a good calcium/ oxalate ratio of 1:1 at pH 4.5. This indicates that the leaves are a good source of calcium, however, the presence of oxalic acid may effect the nutritive value (Anon, 1976) (Table 2.10).

Table 2.10 Chemical composition of tender leaves and flowers of tamarind

Constituent	Tender leaves %	Flowers %
Moisture	70.5-78.0	80.0
Proteins	4.0-5.8	2.8
Fat/oil	1.2-2.1	1.5
Fibre	1.9-3.0	1.5
Carbohydrates (total)	16.0-18.0	
Ash/minerals	1.0-1.5	0.7
Calcium (mg)	101-250	35.5
Magnesium (mg)	71.0	
Phosphorus (mg)	140.0	45.6
Iron (mg)	2.0-5.2	1.5
Copper (mg)	2.0	
Chlorine (mg)	94.0	
Sulphur (mg)	63.0	
Thiamine (mg)	0.1-0.2	0.07
Riboflavin (mg)	0.1-0.2	0.14
Niacin (mg)	1.5-4.1	1.14
Vitamin C (mg)	3.0-6.0	13.80
Carotenes (mg)		0.31
Sodium (mg)	8.0	
Potassium (mg)	270.0	
β-carotene (μg)	2500	
Calories (Kcal)	75.0	
Oxalic acid (mg)	196.0	

Source: Lewis and Neelakantan (1964 a); Anon (1976); Duke (1981)

The leaves are also used as fodder for domestic animals and by wild animals, including elephants. According to Kaitho *et al.* (1988), crude protein content of the fodder tends to vary with the locality and season. Wild animals prefer tamarind leaves to other fodders due to its high crude protein (12-15%)

content. The composition of tamarind leaves as a browse species collected in Ethiopia has been reported by Kaitho *et al.* (1988) (Table 2.11). Leaves are also used to produce an essential oil. This is primarily limonene (24-6%) and benzyl benzoate (40-6%) according to Pino *et al.* (2002).

Table 2.11 Average chemical composition of tamarind leaves used for browse

Constituent	Amount (g/kg)
Organic matter	949
Crude Protein	139
Nitrogen solubility	317
Neutral detergent fibre	467
NDF-bound nitrogen	22
Acid detergent fibre	324
ADF bound nitrogen	14
Lignin	121
Total phenols	14
Condensed tannins	8

Source: Kaitho *et al*. (1988)

2.5 Wood and Bark

In most producing countries the wood is highly valued although most trees produce little heartwood (Chaturvedi, 1985) and it may be absent altogether in young trees. In old trees, the heartwood is generally narrow, hard to very hard, fibrous, heavy and strong, and is regarded as very durable. The specific gravity of the wood ranges from 0.80-0.90 g/m^3. It is purplish brown or mottled brown in colour, dark-reddish veined with an irregular outline and radiating ramifications. It resembles ebony (Dalziel, 1937; Eggeling and Dale, 1951; Bolza and Keating, 1972). The sapwood is up to 20 cm wide; light yellow, sometimes red-streaked, rather fibrous and loosely grained, easily perishable (Kurz, 1877; Troup, 1909). The sapwood is liable to insect attack but the heartwood is durable and termite resistant (Timyan, 1996). The wood quality can be correlated to a degree with the cambial activity and development in relation to the climate of growth (Rao and Rajput, 2001). The bark is sometimes used in traditional medicinal preparations. In terms of constituents it lacks phenols and flavonoids (Neetu and Bohra, 2003).

Chapter 3. Uses and Products

Revised by J.T. Williams

3.1 Introduction

Tamarind is a versatile fruit, which can be used for many purposes. The unique sweet/sour flavour of the pulp is popular in cooking and flavouring. Virtually every part of the tree (wood, root, leaves, bark and fruits) has some value in the subsistence of rural people and a number of commercial applications are well known; others have the potential for further development.

3.2 Agroforestry and land use

Tamarind is used in agroforestry systems in many parts of the tropics due to its multiple uses. In India, many farmers integrate several species, including tamarind, with their agricultural crops and livestock. The increasing integration of tamarind with other trees and crops on farmlands offers a strategy to minimise the risk of crop failure. Tamarind is also an important tree in home gardens in south and southeast Asia.

In agroforestry systems in Maharastra, India, tamarind side branches are trimmed regularly providing fodder for the animals and simultaneously opening a greater space for the inter-mixed crops (Relwani, 1993). In Thailand, intercropping with annuals, such as groundnuts, maize, soybean and beans, is practised in sweet tamarind orchards when the trees are young. In some districts such as Pak Chong in Nakhon Ratchasima province, tamarind is intercropped with custard apple (*Annona* spp.). In the dry season custard apple becomes dormant like tamarind forming a compatible combination (Yaacob and Subhadrabandhu, 1995). Intercropping of tamarind with annual crops can enhance farm income and improve the well being of rural populations, by providing a constant income from the farming system. Once the tamarind tree has passed its juvenile stage and comes into bearing, it will provide a constant supply of fruit, in addition to the produce from the annual crop species. In this way, the farmer obtains more from the same area of land. Tamarind comes into bearing after 10-14 years and for up to eight years of age intercropping is suitable but less so for vegetatively propagated trees which come into bearing at 4-7-10 years.

Tamarind leaf extracts, however, have been reported to reduce mitotic activity and induce chromosomal aberrations in *Allium sativum* root meristems (Yadev, 1986). In Southwest Madagascar, the fallen leaves of tamarind, when placed in the planting holes of corn, reduced emergence and grain yield, indicating an allelopathic effect. Mulching with tamarind leaves is therefore, not advisable (Maille, 1991), although traditionally leaves have been used as mulch material for tobacco cultivation in some countries. Because of the allelopathic effect of tamarind, mixed plantations have not been recommended by Gamble (1922) and Yadev (1986), however in India, to prevent such undesirable effects, tamarind is planted at a wider spacing, commonly 8m x 8m, 8m x 12 m and 12m x 12m (Jambulingam and Fernandes, 1986). Also in the forest-village system of Thailand, where taunga is practised in teak (*Tectona grandis*) plantations, interplanted mixtures with tamarind have been successful (Jordan and Gajaseni, 1990; Dagar *et al*., 1995). The Central Salinity Research Institute in Karnal, India, has demonstrated the advantages of interplanting agricultural crops, including rice, pearl millet and mustard with tamarind, yield reduction was minimal compared to other forest tree species such as Maharukh (*Ailanthus excelsa*) and teak (*Tectonia grandis*). In such mixed cropping systems, tamarind also benefits by receiving supplemental irrigation, weeding and other cultural practices (Dagar *et al.,* 1995). There has been a substantial body of research on the allelopathetic effects of tamarind in relation to intercrops and weed control (Channal *et al*., 2002, 2002a; Parvez *et al.*, 2003, 2003 a).

Tamarind trees are widely used in India and Sri Lanka as ornamentals and shade trees, planted along avenues, roadsides, in parks and along river banks (Meghwal, 1997) and have become popular in the United States as a tree for indoor ornamentation (NAS, 1979). On a more practical note, tamarind trees have been used as windbreaks due to their resistance to storms, however, there are some disadvantages to using tamarind in this way. This has been demonstrated by Rodriguez *et al.* (1985) when the yield of Valencia orange trees (*Citrus sinensis*) growing adjacent to a tamarind windbreak, decreased by 50% due to competition. Tamarind also provides a heavy shade due to its broad spreading crown. By raising the tamarind trees along field boundaries the crop suffers from less shade and competition. Tamarind is also used as a firebreak in Mysore as no grass grows under the tree due to heavy shade. In some parts of India it is thus planted around forest margins to act as a firebreak (Troup, 1921; Salim *et al.*, 1998).

3.3 Socio – cultural aspects

In India and the Far East since ancient times, members of the flora and fauna were identified with particular personalities of the Hindu pantheon and worshipped. Tamarind is such a highly sacred and worshipped tree. These beliefs and practices continue even today in certain sections of society, particularly among the rural folk and aboriginal tribes living in the forest. Nature worship and the faith of these peoples have helped to conserve many natural ecosystems in India. These people have preserved many forest trees such as tamarind and sacred groves are conserved in their original form (Singha, 1995). In some localities of India the tamarind tree is considered to be haunted by spirits and is worshipped on a day called 'Amli Agiaras'. Hindus may also tie a tamarind tree to a mango tree before eating the fruits of the latter and in effect 'marry' the species.

The natives of India consider that the neighbourhoods in which tamarind trees grow become unwholesome, and that it is unsafe to sleep under the tree owing to the acid they exhale during the night (Grieve, 1995). According to Morton (1987), few plants survive beneath the tamarind tree due to its heavy shade and there is a superstition that it is harmful to sleep or to tie a horse beneath the tree, due to the corrosive effect that fallen leaves have on fabrics in damp weather. Tamarind is also used to forecast the weather conditions by the tribal societies in Rajasthan, India. When the fruit is longer than usual, splendid weather with abundant rain is forecast promising high yields of grain and pulse crops (Joshi, 1985).

Some African tribes also venerate the tamarind tree as sacred. In Malawi, tamarind bark soaked with corn is given to domestic fowl in the belief that, if they stray or are stolen, it will induce them to return home. To certain Burmese, the tree represents the dwelling-place of the rain god and some hold the belief that the tree raises the temperature in its immediate vicinity. In Malaya, a little tamarind and coconut milk is placed in the mouth of an infant at birth, and the bark and fruit are given to elephants to make them wise.

3.4 Fruit and Food Products

3.4.1 Pulp

Tamarind is valued mostly for its fruit especially the pulp, which is used for a wide variety of domestic and industrial purposes (Kulkarni *et al.*, 1993). Tamarind is not generally a dessert fruit, although the sweet tamarind is often eaten fresh directly from the pod, almost always so in the West Indies and other parts of MesoAmerica. Fully grown but still unripe fruits are also eaten in the Bahamas; known as 'swells', they are roasted in coal, the skin is then peeled back and the sizzling pulp is dipped in wood ash and eaten (Morton, 1987). The pulp is usually removed from the pod and used to prepare juice, jam, syrup and candy. In Asia however, the immature green pods are often eaten by children and adults dipped in salt as a snack.

More commonly, the acidic pulp is used as a favourite ingredient in culinary preparations such as curries, chutneys, sauces, ice cream and sherbet in countries where the tree grows naturally (Dalziel, 1937; Eggeling and Dale, 1951; Little and Wadsworth, 1964). In Sri Lanka, tamarind is widely used in cuisine as an alternative to lime and also in pickles and chutneys (Jayaweera, 1981). It is also used in India, to make 'tamarind fish', a sea-food pickle, which is considered a great delicacy. Immature tender pods are used as seasoning for cooked rice, meat and fish and delicious sauces for duck, waterfowl and geese are also prepared. In Eastern African countries, the pulp is cooked and made into a porridge called ‘ugali’ made from sorghum or maize flour or dissolved to make a sweet drink.

Tamarind pulp is often made into a juice, infusion or brine. In Ghana, a bitter infusion of the pods is used for cooking cereals and is often added to the water in which poisonous yams are soaked to detoxify them. In India the juice is used to preserve fish, which can be preserved for up to six months when mixed with acetic acid. Tamarind is used in this way in Sri Lanka and many other Asian countries (Macmillan 1943). The juice is also an ingredient of Worcestershire and other barbecue sauces, commonly used in European and North American countries (NAS, 1979).

Tamarind drink is popular in many countries around the world, though there are many different recipes. In some African countries the pulp juice is mixed with wood ash to neutralise the sour taste of the tartaric acid, but the common method is to add sugar to make a pleasantly acid drink. In Ghana, the pulp is mixed with sugar and honey to make a sweet drink. ‘Jugo’ and ‘fresco de tamarindo’ are favourite tamarind drinks in South America (FAO, 1988), and the fruit finds much use as a flavour for guava jelly. Most of the producing countries manufacture drinks commercially. Sometimes it is fermented into an alcoholic beverage (FAO, 1988).

In the Philippines, Sri Lanka and Thailand, fibres are removed from the fruit pulp, which is mixed with sugar, wrapped in paper and sold as toffees. Sellers of these are a common sight in front of schools and on urban roadsides. The pulp is also used to make sweet meats mixed with sugar called ‘tamarind balls’ (Purseglove, 1987); in Senegal, they are called ‘bengal’. Similarly in India, the pulp is eaten raw and sweetened with sugar (Lotschert and Beese, 1994). It is desirable to remove the pulp without using water when the pulp is used in confectionery.

3.4.2 Seed

Tamarind seed is a by-product of the commercial utilisation of the fruit, however it has several uses. In the past, the seeds have been wasted. In 1942, two Indian scientists, T.P. Ghose and S. Krishna, announced that the decorticated kernels contained 46-48% of a gel-forming substance. Dr G. R. Savur of the Pectin Manufacturing Company, Bombay, patented a process for the production of a purified product, called ‘jellose’, ‘polyose’, or ‘pectin’, which was found to be superior to other methods of fruit preservation. The substance gelatinises with sugar concentrates even in cold water or milk (Savur, 1948). The name ‘jellose’ has been suggested for this polysaccharide as it describes both its jelly forming properties and the carbohydrate character (Rao, 1948, 1956). It has been recommended for use as a stabiliser in ice cream, mayonnaise and cheese and as an ingredient or agent in a number of pharmaceutical products (Morton, 1987). Presently, it is used in food and in industrial applications. Tamarind jellose has not been fully exploited, but due to its abundance and cheapness, seed jellose has great potential for replacing fruit pectins in many industries.

The presence of tannins and other colouring matter in the testa make the whole seed unsuitable for human consumption. Therefore, the testa has to be separated from the kernels by boiling or roasting. Otherwise, such side effects as depression, constipation and gastro-intestinal disorders may result (Anon, 1976). In Gambia, seeds are pounded and eaten in times of famine. In India, seed kernels are used in times of food scarcity in the districts of Chennai, Andhra and Madhya Pradesh and elsewhere, either alone or mixed with cereal flours (Shankaracharya, 1998). The seeds are also eaten after removal of the testa after roasting or boiling. In India, village women roast the seeds and chew them instead of betel nut (FAO, 1988). The roasted seeds are claimed to be superior for to peanuts in flavour (Pratt and del Rosario, 1913) and are also used as a substitute or adulterant to coffee. Sometimes they are made into flour for bread, Indian chapattis and cake making (Purseglove, 1987).

The seed is also used in the vegetable and food processing industries. Tamarind xyloglucan, commonly known as 'tamarind gum', is the major component of TKP. It forms a stiff gel and is used for thickening, stabilising and gelling in food. It is commercially available as a food additive for improving the viscosity and texture of processed foods (Sone and Sato, 1994). Bhattacharyya *et al.* (1994) reported that the incorporation of TKP decreased the specific volume and springiness of bread, in contrast to increased hardness, while cohesiveness remained unaffected. Incorporation of TKP also affects the hardness, crispness and thickness of biscuits, while the flavour and taste were unaffected. In both bread and biscuits the incorporation of TKP up to 15% was acceptable. Low cost TKP, with a jelly grade of 80 and 85, could be used as a substitute for costly pectin for making jellies, jams and marmalades.

Seeds give an amber coloured oil, free of smell and sweet to taste, which resembles linseed oil. It could be used for making varnishes, paints and burning in oil lamps (Watt, 1893). In Bengal, the oil is used for making varnish to paint idols (Rama Rao, 1975; Anon, 1976) and light lamps (Lewis and Neelakantan, 1964 a; Salim *et al.,* 1998). The oil is said to be palatable and of culinary quality (Morton, 1987).

Tamarind seed has shown a relatively high level of *in vitro* protein digestibility. The proteins have a favourable amino acid composition and could supplement cereals and legumes poor in methionine and cystine. They also contain small amounts of anti-nutritional factors (tannins, phytic acid, hydrogen cyanide, trypsin inhibitor activity and phytohaemaglutinating activity). Seeds could be used as a cheaper source of protein to alleviate protein malnutrition which is widespread in many developing countries (Sidduhuraju *et al.*, 1995).

In most countries the seeds are wasted even though they could be ground to make a palatable livestock feed (NAS, 1979). The seeds are difficult to grind due to the hard testa, which can be slightly eased by boiling, followed by decortication. This may account for its low utilisation in livestock feed. In feeding trials, the performance of chickens, however, has been unsatisfactory. The chicks fed on tamarind diets had higher water intakes than the controls and the pancreas weight and intestinal and caecal lengths were also increased (de Lumen *et al.*, 1986). Panigrahi *et al.* (1989) suggested that the poor utilisation of tamarind seed meal by chickens may be due to the indigestible nature of the polysaccharide, rather than its tannin content, or possibly the presence of other toxins. However, tamarind seed meal could be used in the diet of growing pigs, replacing up to 75% of maize without affecting nutrient utilisation (Rao *et al.,* 1989). Other studies show that tamarind seed meal and 10% molasses could completely replace maize in the diet of growing pigs (Reddy *et al.,* 1986). Bhatta *et al*., (2001) have considered that a natural source of tannin from tamarind seed husks can be used to depress gas production in rumen fermentation, particularly in cross-bred dairy cows.

3.4.3 Leaves and Flowers

The leaves, flowers and immature pods of tamarind are also edible. The leaves and flowers are used to make curries, salads, stews and soups in many countries, especially in times of scarcity (Benthall, 1933). In India, leaves are made into a dish called 'Chindar'. The seedlings are also eaten as a vegetable. Young leaves of tamarind are used as a seasoning vegetable in some Thai food recipes because of their sourness and specific aroma (Coronel, 1991). In Zimbabwe, the leaves are added to soup and the flowers used in salads. The children in Gambia mix the acid leaves with gum from fig trees to make a 'chewing gum' (Sozolnoki, 1985). Flowers are an important nectar resource for honeybees in South India. The honey is of golden yellow colour and slightly acidic in flavour (NAS, 1979; Sozolnoki, 1985).

In Thailand chemicals have been used in an attempt to increase production of young leaves for use as a seasoning vegetable. Thiourea, potassium nitrate, 2,4-D and Ethephon have been used to induce the growth of new leaves. Ethephon at 200 ppm concentration was reported to be the best substance for inducing young leaf initiation in tamarind and could be useful for the commercial production of young leaves for the food industry (Yimsawat *et al.,* 1996).

Tamarind leaves are used for fodder and are relished by cattle and goats, although they are rarely used for this purpose in home gardens as harvesting reduces fruit yield. However, tamarind trees growing in woodlands are often eaten by wild animals, such as elephants in Zambia (Kaitho *et al.*, 1988; Storrs, 1995). Ngog Nje (1984) studied the feeding habits of West African giraffe in the Waza National Park in Cameroon and revealed that giraffes browse 22 plant species belonging to 12 families, tamarind is the preferred plant, probably due to its high leaf protein content.

The leaves are used to rear silkworms, *Anephe* spp. in India and *Hypsoides vuilletti* in West Africa. The silk produced is very fine and considered superior for embroidery. Tamarind leaves, flowers and the fruit contain acid and are employed as auxiliaries in dye, especially with safflower. The leaves and flowers are also useful as mordants in dyeing. A yellow dye derived from the leaves colours wool red and turns indigo dyed silk to green (Anon, 1976; Salim *et al.*, 1998). Mature leaves are used as a bleaching agent in the preparation of young leaves of 'buri' *(Corypha alata)* for hat making in the Philippines (Brown, 1954).

3.4.4 Twigs and Bark

After a lapse of more than half a century natural vegetable dyes have regained considerable importance all over the world because of their eco-friendly nature. Many tamarind-producing countries can play a vital role in this field and serve as a potential source for natural dyes. Tamarind bark and leaves contain tannin, with the bark reported to contain up to 70%, which has been used in the tanning industry. It is used for tanning hides and dyeing. Galls on the young branches are also used for tanning (Morton, 1987).

In Zambia, bark tannins are used in the preparation of ink and for fixing dyes (Storrs, 1995). The bark is also burnt to make ink in many other African countries. Tamarind twigs are sometimes used as 'chewsticks' and the bark is also used as a masticatory, alone or in place of lime with betel nut.

3.4.5 Lac

The tamarind tree is a host for the lac insect, *Kerria lacca*, that deposits a resin on the twigs. This product could be harvested and sold as stick-lac for the production of varnishes and lacquers. However, this is not considered an important product and tamarind growers often cut the resinous twigs and discard them.

3.4.6 Wood

Tamarind wood has many uses including making furniture, wheels, mallets, rice pounders, mortars, pestles, ploughs, well construction, tent pegs, canoes, side planks for boats, cart shafts and axles, and naves of wheels, toys, oil presses, sugar presses, printing blocks, tools and tool handles, turnery, etc. (Coates-Palgrave, 1988; Troup, 1909). Tamarind heartwood is considered to be a very durable timber and is used in furniture making as it takes on a good polish (Jayaweera, 1981). However, due to its hardness it is difficult to work and liable to crack during seasoning (Dalziel, 1937; Eggeling and Dale, 1951; Bolza and Keating, 1972; Allen and Allen, 1981; Chaturvedi, 1985). The tree tends to become hollow in the centre as it gets old, and it is therefore difficult to get a tamarind plank of any width. For this reason its value in house construction is limited. People in the French Reunion Islands, however, consider tamarind to be a high quality timber valued for furniture making (Borderes, 1991). In North America, tamarind wood has been traded under the name of 'Madeira mahogany' (NAS, 1979).

The wood is also good fuelwood with a calorific value of 4850 kcal/kg, producing a great heat, which is required for example, in brick making. The wood can be used to make charcoal but other multipurpose trees are preferred (Gohil and Singh, 2003) since they produce a higher dry stem biomass, even though tamarind wood density is high at 850 kg/m^3 (Rao and Sampathrajan, 2001). It is valued for making gunpowder (NAS, 1979; Chaturvedi, 1985; Purseglove, 1987), and it was also used as a major fuel for producer gas (gasogen) units that powered Indian cars and trucks during World War II. In Malaysia, although the trees are seldom felled, they are frequently lopped to obtain firewood (Morton, 1987).

The ash is used to remove hair from animal hides (Dalziel, 1937; Irvine, 1961; Salim *et al*., 1998) and can be mixed with fruit pulp for cleansing and brightening brass and copper vessels.

3.5 Medicinal uses

The medicinal value of tamarind is mentioned in traditional Sanskrit literature. The laxative properties of the pulp and the diuretic properties of the leaf sap have been confirmed by modern medical science (Bueso, 1980). Tamarind fruits were well known in Europe for their medicinal properties, having been introduced by Arab traders from India (Rama Rao, 1975). Tamarind products, leaves, fruits and seeds have been extensively used in traditional Indian and African medicine (Jayaweera, 1981; Parrotta, 1990). Several medicinal properties are claimed for preparations containing tamarind pulp, leaves, flowers, bark and roots (Bueso, 1980).

A number of recent surveys have listed local folk uses of tamarind as remedies for ailments. These include use as anti-inflammatories in North Africa (Rimbau *et al.*, 1999), use as herbal medicines in Burkina Faso (Kristensen and Lykke, 2003), use against leucorrhoea in Orissa, India (Sen and Behera 2000), use for skin disorders in Gujarat (Punjani and Kumar, 2002), and general use in Nanderbar District of Maharasistra State (Patil and Yadav, 2003) and coastal villages in Tamil Nadu (Rajendran *et al.*, 2003). Some specific examples, many long-standing, are described below.

3.5.1 Pulp

Tamarind pulp has long been used for many medicinal purposes and continues to be used by many people in Africa, Asia and America. In former times, the fruit pulp was used as a gentle laxative under the name 'Pulpa tamarindorum'. It is available commercially in tablet form in Thailand for the reduction of excess weight (Bhumibhamon, 1999, Personal Communication). Tamarind pulp alone or in combination with lime juice, honey, milk, dates, spices or camphor is used as a digestive and a carminative, even for elephants, and as a remedy for biliousness and bile disorders and febrile conditions. It is said to improve loss of appetite.

Tamarind has been used in the treatment of a number of ailments, including the alleviation of sunstroke, *Datura* poisoning (Gunasena and Hughes, 2000), and the intoxicating effects of alcohol and 'ganja' (*Cannabis sativa* L.). It is used as a gargle for sore throats, dressing of wounds (Benthall, 1933; Dalziel, 1937; Eggeling and Dale, 1951; Chaturvedi, 1985) and is said to aid the restoration of sensation in cases of paralysis. In Brazil, both the fruit pulp and the leaf are regarded as purgative, diaphoretic and emollient.

Tamarind is also said to aid in the cure of malarial fever (Timyan, 1996). In Southeast Asia, the pulp is prescribed to counteract the ill effects of overdoses of chaulmoogra (*Hydnocarpus anthelmintica* Pierre), which is given to treat leprosy, and in Mauritius, the pulp is used as a liniment for rheumatism.

The fruits are reported to have anti-fungal and anti-bacterial properties (Ray and Majumdar, 1976; Guerin and Reveillere, 1984; Bibitha *et al.*, 2002; Metwali, 2003; John *et al.*, 2004). When the bitter principle is extracted with benzene and subsequently digested with petrol, it yields 0.67% of a brown, odourless liquid named 'tamarindienal', identified as 5-hydroxy 2-oxo-hexa-3,5-dienal (Imbabi *et al.,* 1992 a; 1992 b). It is a potent fungicidal agent to cultures of *Aspergillus niger* and *Candida albicans* and possesses a strong bactericidal activity towards cultures of *Salmonella, Bacillus subtilis*, *Staphylococcus aureus*, *Escherichia coli* and *Pseudomonas aeruginosa*. Extracts from tamarind fruit pulp have also shown molluscicidal activity against *Bulinus trancatus* snails. This activity is believed to be due to the presence of saponins in the fruit (Imbabi and Abu-Al-Futuh, 1992 a). Tamarind plant extracts have been used to purify drinking water in Burkina Faso and Vietnam (Bleach *et al.,* 1991).

Fruit extracts have been shown to enhance the bioavailability of ibuprofen in humans (Garba *et al.*, 2003). Frequent research on aqueous extracts of seeds has shown a strong anti-diabetic effect in rats (Maitin *et al*., 2004).

There is current medical interest in the use of purified xyloglucan from tamarind in eye surgery for conjunctival cell adhesion and corneal wound healing (Burgalassi *et al.*, 2000; Ghelardi *et al.*, 2000). Other medical interest relates to the use of tamarind fruit to manage fluoride toxicity (Khandare *et al.*, 2000). In relation to the xyloglucan, Marry *et al.* (2003) looked at some reaction products and their structural characterisation because of the widespread interest in their use.

3.5.2 Seed

The seed is usually powdered and is 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 (Rama Rao, 1975; Jayaweera, 1981). 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 diarrhoea and jaundice. For external appearance, the testa of the seed macerated with vinegar or lime juice is used on the face to prevent the formation of pimples and in Indonesia, oil extracted from the seed is used as a hair dressing.

The antioxidative activity of tamarind seed was investigated by Osawa *et al*, (1994). They found that an ethanol extract prepared from the seed coat exhibited antioxidative activity as measured by the thiocyanate and thiobarbituric (TBA) method. Ethyl acetate extracts prepared from the seed coat also had strong antioxidant activity. This was confirmed by Luengthanaphol *et al.* (2004). This suggests that tamarind seed coat, a by-product of the tamarind gum industry, could be used as a safe and low-cost source of antioxidant, although other herbals may be more effective (Ramos *et al.*, 2003).

3.5.3 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, coughs, fever, intestinal worms, urinary troubles and liver ailments. Internally, leaves and pulp act as a cholagogue, laxative and are often used in treating 'congestion' of the liver, habitual constipation and haemorrhoids. Leaf extracts also exhibit anti-oxidant activity in the liver. Also taken internally, the leaves are used in cardiac and blood sugar reducing medicines.

Leaves ground into a paste with lime juice and heartwood of *Acacia tundra* Willd. are applied to boils to prevent suppuration and inflammatory swellings. 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).

A sweetened decoction is used in the Philippines, as a cough remedy and filtered juice is used for conjunctivitis. Young leaves are reported to cure other eye infections, sprains and wounds.

3.5.4 Bark, flower and root

The medicinal properties of the bark, flower and root are similar in many respects to the pulp. Treatment for digestive tract ailments and indigestion have been reported from Cambodia, India and the Philippines (Jayaweera, 1981; Rama Rao, 1975). The bark ash is 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 throats, to heal aphthous sores and in urinary discharges and gonorrhoea.

The bark is astringent and is 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 bark of the tree should be peeled off if needed for medicinal purposes during the time when the tree is not flowering or when the flowering season ends. Ashes of the burnt shells of ripe fruits are used as an alkaline substance with other alkaline ashes in the preparation of medicine 'Abayalavana' in India, for curing enlarged spleen.

A poultice of flowers is used in the treatment of eye diseases and conjunctivitis in the Philippines (Brown, 1954; de Padua *et al.,*1978). The flowers are also used internally as a remedy for jaundice and bleeding piles.

The 'Irula' tribals of the Anaikkatty hills in the northwest of Coimbatore, Tamil Nadu, India, use tamarind root bark for abortion and for prevention of pregnancies. The root bark is ground into a powder and mixed with hot water and administered three days before abortions and for prevention of pregnancies (Lakshmanan and Narayanan, 1994).

3.5.5 Veterinary use

Atawodi *et al.* (2002) reported on the use of tamarind for treating trypanosomiosis in domestic animals in Kaduna, Nigeria. Indigenous knowledge revealed the use of tamarind and *Adamsonia digitata*, *Terminalia avicennoides, Khaya senegalensis, Steruelia setigera* in various combinations.

Chungsamarnyart and Junsawan (2001) have shown that a crude extract of tamarind fruits in water with 10% ethanol, 1:2 and 1:5 weight/volume used for seven days can be used as a dip against the engorged female cattle tick, *Boophilus microphus.* The active substances are the organic acids, especially oxalic and tartaric.

The pulp is also effective in ridding domestic animals of pests in Colombia, through the application of pulp with butter and other ingredients (Morton, 1987).

3.6 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, 1982 a; 1982 b). Tamarind Kernel Powder produced from seeds is another commercial product and is often reported upon in commercial digests (e.g. Mathur and Mathur, 2001).

Fruits can be processed using machines to dehull, deseed and defibre them. The use of a mechanical dehulling unit resulted in higher dehulling frequency than the traditional fruit beating. Costs and processing times are also lower. Mechanical deseeding is eight times faster than manual use of a mallet and mechanical defibring is seven times faster (Sharanakumar *et al.,* 2001).

3.6.1 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 pulverising the creamy white kernels. The decorticated seed is ground by machines to the required mesh size to obtain a yield of 55-60%. The powder tends to deteriorate during storage under humid conditions, hence storage in a dry place in moisture proof containers is important. Mixing with 0.5% of sodium bisulphite before packing will prevent enzymatic deterioration. The TKP will become rancid and brown if stored inadequately and the storage ability and colour will be better if it is defatted (Sivarama Reddy *et al.*, 1979). The general characteristic of a good tamarind seed powder is that it should have the characteristic flavouring when dissolved in water and be free of any burnt or other undesirable flavours; it should have good keeping quality and be free from any insect pests, fungal growth or extraneous materials.

The TKP, when boiled in water containing boric acid and phenol as preservatives, gives a very good paper adhesive (Anon, 1976). In India, TKP is used as a source of carbohydrate for the adhesive or binding agent in paper and textile sizing, and weaving and jute products (Anon, 1976; Shankaracharya, 1998) as well as textile printing (Khoja and Halbe (2001). The sizing property of TKP is due to the presence of up to 60% of the polysaccharide. A high grade adhesive from tamarind seed kernels could be prepared by roasting the seeds at 110° C for 15 minutes, de-hulling to remove the testa, powdering and passing through a 180 mesh sieve and making a porridge by boiling with water. Then it is mixed with 200% hot water, 5% glucose and 12% sodium bicarbonate and is ready for use (Devadas and Gothandapani, 1993).

TKP can be mixed with other concentrates to make ca. 25% manufactured cattle feed. Another commercial application can be in production of varnish (Kumar and Sethuraman, 2000), and TKP can be used as a vegetable clarifier (Mungare *et al*., 2001).

3.6.2 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 pectins. However, unlike fruit pectin, tamarind polysaccharide can form gels over a wide pH range, including neutral and basic conditions. Tamarind polysaccharides are also not affected by boiling in neutral aqueous solutions, even if boiled for long periods. Fruit pectins undergo degradation on boiling and fall to one-third of their original value after one hour of boiling. Therefore tamarind polysaccharide can be useful as a gel formation agent, and may be substituted for fruit pectins. Tamarind polysaccharide does not contain galacturonic acid and methyluronate and is therefore not regarded as a true pectin; it is termed ‘jellose’ (Rao, 1948).

Marathe *et al.* (2002) compare the gelling behaviour of ‘jellose’ or polyose which was isolated from tamarind kernel powder (TKP) in 50% yield by alcohol extraction of an acidified boiled aqueous extract subsequently dried and pulverised. The gelling behaviour of polyose vis-à-vis pectin, and its blends with pectin was studied in a 65° Brix sucrose solute as a function of pH and concentration. One per cent pectin gave a good firm gel, while 80:20 and 60:40 blends of pectin/polyose gave a firm gel at 1.5 and 2.0% respectively. A 40:60, 20:80 and 0:100 blend of pectin polyose gave a good set at 2.0% beyond which the jellies were hard and difficult to chew. Two per cent polyose from TKP adequately substitutes 1% pectin in ready-to-eat jelly.

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%. It is then stirred vigorously and boiled for a further 30-40 minutes. The solution is kept overnight for setting and the supernatant liquid is siphoned off and concentrated under vacuum, passed through a filter press and then dried in a drum drier. The resultant product is pulverised in a ball mill. A good sample of jellose should have a relative viscosity of 5.0% at 35º C in 0.5% solution, which is somewhat higher than corn starch. Jellose is much cheaper than corn starch and is required in smaller quantities.

An invention for the extraction of polysaccharides from seed kernels has been developed and patented by Gordon (1968). As the pulp also contains pectin, an integrated process has been developed for the production of pectin, tartarates and ethanol. In this process, the pulp is repeatedly extracted with boiling water and the filtered extract is cooled to separate potassium bitartarate. The supplement is concentrated under vacuum and the pectin is separated by the addition of alcohol. The filtrate, after recovering the alcohol, is treated with lime to precipitate calcium tartarate. The remaining sugars are fermented with yeast and alcohol is recovered. The recovery is about 2.5% pectin, in addition to 12% tartaric acid and 12% alcohol, which makes the process economic and attractive. Krishna (1955) reported a process for the extraction of tartarates with acidified ethanol and subsequent extraction of pectin. After removing the alcohol, the residual syrup could be used for edible purposes. This process has been patented under the Indian Bureau of Standards, Indian Patent No: 52, 1955. Tamarind pectin resembles apple pectin and has the following composition (Table 3.1).

Table 3.1 Average chemical composition of tamarind pectin

Constituent	Per cent
Moisture	7.7-8.9
Ash	2.3-3.0
Calcium pectate	70.0-80.4
Methoxyl	7.9-9.9
Uronic acid	43.0-56.4

3.6.3 Tamarind juice concentrate

Tamarind juice concentrate (TJC) is a convenient product, as it is easy to dissolve and reconstitute in hot water (Anon, 1982 b). It can also be stored for long periods. Tamarind juice concentrate is prepared by extracting cleaned pulp with boiling water using the counter current principle, where dilute extracts are used for extracting fresh batches of the pulp. Using this process, an extract is obtained containing 20% soluble solids. The extract is separated from the pulp by sieving and is concentrated under vacuum in a forced circulation evaporator. When the soluble solids reach 68%, the pulp is placed in cans or bottles. It sets like jam on cooling. The yield of the concentrate is about 75% of the pulp used. (Table 3.2) The quality of the product is assured by using recently harvested fruits free from insect and rodent damage (Lewis *et al.,* 1964 a). An Indian Standard is available for TJC (IS: 5955; 1993) developed to maintain the quality of the product.

Table 3.2 Chemical composition of tamarind juice concentrate and tamarind pulp powder (%)

Constituent	Tamarind juice concentrate (TJC)	Tamarind pulp powder (TPP)
Moisture	30.0	3.5-8.8
Tartaric acid (total)	13.0	8.7-11.1
Invert sugars	50.0	15.8-25.0
Proteins	2.0	1.7-2.4
Starch		20.0-41.3
Ash		2.1-3.2
Crude fibre	2.0	

Source: Nagaraja *et al*., (1975); Manjunath *et al*., (1991)

Kotecha and Kadam (2003 a) studied the stability of beverages and TJC. Fully matured tamarind fruits were obtained from a local market in Rahuri, Maharashtra, India. The juice and pulp extracted from the fruits were used to produce ready-to-serve (RTS) beverage, syrup and TJC. The products were stored at ambient (33.8±7.4 °C, RH 74.2±23.8%) and low (7±2 °C, RH 90-95%, temperatures for 180 days. The changes in chemical composition and acceptability were analysed. Results showed that TSS, titratable acidity and total sugar content of RTS beverages stored at both temperatures increased, whereas ascorbic acid content decreased. A gradual increase in TSS, titratable acidity and total sugars, as well as a slight decrease in ascorbic acid content were observed for syrups stored at both temperatures. The rate of increase or decrease was higher in syrup stored at ambient conditions. A gradual increase in TSS was observed in the juice concentrates stored at both temperatures. Titratable acidity and total sugar content also increased, while ascorbic acid content decreased. The overall acceptability scores for the three types of products decreased during storage. The RTS beverage and juice concentrate stored at ambient conditions obtained lower scores compared to those stored at low temperature. Syrups stored at both ambient and low temperatures remained acceptable for 180 days.

3.6.4 Tamarind pulp powder

Tamarind pulp cannot be kept indefinitely because of browning in storage due to phenolics and non enzymatic browning (Kotecha and Kadam, 2003 b). Here it is processed into pulp powder.

Tamarind Pulp Powder (TPP) is prepared by concentrating, drying and milling the pulp into a powder form. It is one of the convenience food products produced commercially by several manufacturers in India. Depending on the manufacturing process, wide variations in the physico-chemical characteristics are reported (Table 3.2). Manjunath *et al.* (1991) reported that on average the total solid content of tamarind pulp powder varied from 18.6-25%, acidity from 8.7-11.1% with an average value of 9.9% (as tartaric acid). The moisture content ranges from 3.5-8.8%. Among the minerals, the calcium and potassium contents were high and ranged from 74-143 mg and 23.8-27.7 mg. Starch is the major ingredient in tamarind pulp powder (20-41%).

On a small scale, the fruit pulp is made into a refreshing drink after dissolving in water and squeezing by hand. After removing the extraneous matter, water is added to dilute the drink as required. Tamarind pulp is enjoyed as a refreshing drink and beverage in most of the Southern and Central American and Asian countries. Modern food technology has greatly advanced the preservation and utilisation of tamarind fruit. Tamarind drinks in polypacks are commercially available in Thailand, Indonesia, and many countries of Africa. In Mexico and Guatemala, the drink is carbonated. It has a high content of vitamin B (thiamine and niacin) as well as small amounts of vitamin C (ascorbic acid) and carotene (Sozolnoki, 1985). Tamarind fruit juice is most valued for its ascorbic acid content, which is about 5.1-6.1 mg/100ml. Coates-Palgrave (1988) quotes a recipe of Dr WJ. Eggeling in *The Indigenous Trees of the Uganda Protectorate* (Eggeling and Dale, 1951) as follows; 'To 60 grams of the pulp add one litre of cold water and a little sugar, stir and leave in a cool place to mature for seven days'. Tamarind has been used as a beverage in Africa for a long period on a small scale.

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). The pulping operation consists of breaking the shells by hand and agitation in water to separate the pulp and the seeds. The industrial method used in India for the manufacture of tamarind juice concentrate is by extraction of all the solubles from the fruit pulp in boiling water (Nagaraja *et al.,* 1975). The recommended concentration of tamarind pulp in syrup is between 20-24%, so as to produce a beverage with distinctive flavour and acidity (Tarber, 1915; Bueso, 1980). Such syrup contains 56.7% total solids, 43.8% reducing sugars and a total acidity of 1.11% as tartaric acid. A clarified tamarind juice is one in which the structural and colloidal phases are broken to prevent sedimentation which can be done by adding gelatine (Baragano de Mosqueda, 1980). In this process, 0.12-0.15% gelatine is agitated with the pulp and left to stand for 10-15 days at 10° C. The colloidal particles will precipitate during this period and are removed by decantation. The juice maintains good colour and flavour and is transparent. Bueso (1980) also prepared a blended tamarind and a soursop (*Annona muricata*) drink, which had commercial acceptance. The tamarind drink contained 9-12% pulp and was adjusted to 21.5° Brix. The blended drink had 10-14% pulp and 15° and 17° Brix. The drink after pasteurisation at 185-190° F was canned. The tamarind drink remained in good condition after one year and the blended drink for 10 months when stored at 29.4° C.

Other authors have also developed processes to prepare drinks, syrup, juice, liquor and solid extracts from tamarind pulp. Girdhari *et al.* (1958) have developed formulae for preparing spiced sauces and beverages from the pulp. Zablocki and Pecore (1995) described a process for using tamarind extract as a replacement for phosphoric acid, citric acid and other acids added to soft drinks. Benk (1987), Latno and Vega (1986) and Sanchez (1985) have used tamarind pulp for making wine-like beverages. In Malaysia, tamarind pulp has been used for making country wine but its commercial production has been constrained due to the lack of reliable supplies of wine yeast and equipment required for re-useable processing.

3.6.5 Tamarind pickle

Pulp is used commercially to prepare tamarind pickle. The pickles are commonly used in Asia as an accompaniment to curries or other main meals. Pickles are hot, spicy and have a salty-sour taste, and can be preserved for several months. Preservation is due to the presence of salt, increased acidity and spices. The preparations of pickles are simple and can be done at a household level.

When making pickles, fresh mature tamarind fruits are selected and soaked in clean water for 12 hours and the pulp is separated. For each kilogram of tamarind, one kilogram of sugar is added and boiled, stirring the mixture continuously. Then mixtures of spices are added. Spice mixture for one kilogram of tamarind should include the following: 40 g coriander, 50 g cumin seed, 30 g black cumin, 3-4 cloves, 3-4 pieces of cardamom, 3-4 pieces of cinnamon, 10-12 chillies, 30 g salt, 250 ml mustard oil and 30 g black pepper. These are ground into a paste and added to the boiling tamarind and mixed thoroughly. The product is then packed into pre-sterilised glass jars or plastic bags and allowed to cool at room temperature. The pickle can be stored in small polythene bags or in clean jars and sealed. It will keep well if stored in a cool place. Care should be taken to prevent air bubbles becoming trapped in the pickle and to ensure that a layer of oil covers the product. Tamarind pickle is available in the urban markets of Bangladesh, India and Sri Lanka and is rated as a popular product of tamarind.

3.6.6 Construction

The seed is also used as a filler for adhesives in the plywood industry and a stabiliser for bricks, as a binder for sawdust briquettes and a thickener for some explosives. Ground, boiled and mixed with gum, the seeds produce a strong wood cement (Benthall, 1933; Rama Rao, 1975). A composite material of tamarind seed gum and the cellulose rich sisal plant fibre was prepared by Veluraja *et al.* (1997) by a process of humidification and compression to increase its strength. This material is suitable for construction applications such as false roofing and room partitioning.

3.6.7 Paper making

Use of xyloglucans as alternatives to currently used wet-end additives in paper making were studied by Lima *et al.*, (2003). Xyloglucans improved the mechanical properties of paper sheets without affecting the optical ones. Addition of 1% (w/w) of hemicelluloses to cellulosic pulp was able to increase by about 30% the mechanical properties such as burst and tear indexes. Seeds of several species could be used as sources for the production of wet-end additives since the results did not vary with the source of the polysaccharides. Even if the utilisation of these hemicelluloses will not cost less than starch or guar gum, it might represent an important strategy for sustainable use of rainforest species.

3.7 Examples of household recipes

Jam: In making tamarind jam, ripe fruits are shelled and the pulp is boiled for 10 minutes. 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, sterilised jars and sealed.

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 minutes. The cooled syrup is poured into sterilised bottles and sealed.

Candy: Sweetened tamarind fruit is made by peeling whole ripe fruits and pouring boiling (62° C) sugar syrup over the fruits and placing in a deep enamel basin. Boiling syrup is prepared by mixing three parts sugar with one part water. After soaking for three 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. The sweetened fruits are arranged on bamboo racks, dried in the sun and covered with a wire screen to keep off flies. Final drying is done in an oven at a low temperature. After cooling the dry fruits are wrapped in cellophane.

Champoy: Tamarind fruits may also be processed into balls or 'champoy' which is a common tamarind product in the Philippines. To one cup of pulp with seeds are added two cups of boiled and mashed sweet potato (*Ipomea batatas*), two cups of sugar, one-eighth cup of salt and one cup of water. The mixture is cooked in a moderate fire with constant stirring until it becomes thick and may be shaped into balls. The balls are rolled in sugar and wrapped in cellophane.

Ade: This is a refreshing tamarind drink prepared in the Philippines and some tropical American countries by mixing ripe pulp with sugar and water until the desired taste is attained. The simple home method of making Ade is to shell the fruits, placing them in 2-3 litres of water and allow it to stand for a short time, then adding a tablespoonful of sugar and shaking vigorously. For a richer beverage the shelled tamarind should be covered with hot sugar syrup and allowed to stand for several days and finally diluted to the required strength with iced water and strained. Sometimes spicy seasonings, such as cloves, cinnamon, ginger, pepper or lime slices, are added to improve the taste (Morton, 1987). In Brazil, Ade is prepared by covering the shelled fruits in cold water for 10-12 days, then the seeds are removed and strained and a cup of sugar is added to every two cups of pulp. The mixture is boiled for 15-20 minutes and placed into glass jars topped with paraffin and diluted as desired. It is a popular drink in the tropics of America and it is bottled in carbonated form in Guatemala, Mexico and Puerto Rico.

3.8 Other uses

Tamarind fruits and other extracts from the tree have a number of reported miscellaneous uses which are still used widely. Tamarind pulp mixed with sea salt has been reported to polish brass, copper and silver in Sri Lanka (Jayaweera, 1981), India (Benthall, 1933; Eggeling and Dale, 1951; Coates-Palgrave, 1988), West Africa (Morton, 1987), South Africa and Somalia (Mahony, 1990). In West Africa, an infusion of the whole pod is added to the dye when colouring goat hides. The fruit pulp may be used as a fixative with turmeric (*Curcuma longa*) and annatto (*Bixa orellana*) in dyeing, and it also serves to coagulate rubber latex.

The seed testa contains 23% tannin, which when suitably blended is used for tanning leather and imparting colour-fast shades to wool. In leather tanning tests, tamarind tannin gives a harsh and highly coloured leather which is not suitable for shoe uppers, but could be used for heavy soles, suitcases etc.

The seed husk has also been found to be an effective fish poison (Roy *et al.,* 1987). Jena (1991) reported that powdered seed husks added to water, even at low dosages of 5-10 mg/litre, killed several fish species, *Labeo rohita, Calta calta, Cirrhinus mrigala, Cyprinus carpio, Oreochromis mossabicus* and *Channa marlius,* within two hours of its application.

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). The unfolded leaves of tamarind, containing lupeol, are said to be effective in inhibiting viral and fungal diseases in plants. Extracts of tamarind are being looked at for their use in controlling pests and diseases eg, control of citrus canker in Thailand (Leksomboon *et al.*, 2001), of root knot nematode (Ranjana and Rajendra, 2001) and of a range of fungi (John *et al.*, 2004, Neetu and Bohra, 2003). Triterpenoids, phenols and alkaloids are all involved.

3.9 Tamarind Patents

Several tamarind related patents have been developed since 1974. Eight were issued in India and these relate to the preparation of TKP as a sizing agent, tannin material, preparation of gum, preparation of juice and health care applications. The US Patent and Trademark Office (USPTO) granted thirty patents between 1978 and 1997. Eight of those thirty patents are owned by Merck & Co, and relate mainly to the utilisation of TKP as a gum and binding agent. This is an indication of the untapped potential of tamarind and its scope for industrial exploitation.

Table 3.3 Patents on processes, products and uses of tamarind

Patents granted/ Application field	Assignee/Applicant	Year
Patents granted (India)		
Method of preparation of tamarind powder	Chankrapani S. and Chankrapani J.	1974
A new process for the preparation of TKP	CISIR	1974
A simple process for obtaining a good tanning material from tamarind seed testa	CISIR	1978
Purification of tamarind gum by air classification	General Mills Chemicals Inc.	1979
A enzymatic process for the preparation of tamarind juice concentrate	CISIR	1985
Patents application (India)		
Process for making tamarind Pickles	Dilip Shanthnaran Dahanukar	1995
A process for preparing tamarind extract in the form of paste/jam	Shoki Kobayashi	1996
A manufacturing process for tamarind paste and concentrate	Yelantinaga	1996
A new process for recovery of tartaric acid and other products from tamarind pulp	CISIR	1996
Patents granted (USPTO)		
Purification of tamarind gum	General mills Chemicals Inc., USA	1978
Use of TKP as an anti-migrant	Merck & Co. Inc. USA	1982
Clarified tamarind kernel powder	Merck & Co. Inc., USA	1984

Patents granted (USPTO)	Assignee/Applicant	Year
Process for separating polysaccharides from tamarind seeds	Shikibo Ltd., Japan	1990
Methods for preparing tamarind oligosaccharides	Lafayette Applied Chemistry Inc., USA	1995
Beverages using tamarind extract and methods of making such beverages	Nutra Sweet Co., USA	1995

Source: TIFAC Bulletin – Intellectual Property Rights (IPR) Vol.3 No.9 1997.

Chapter 4. Ecological Requirements

Revised by J.T. Williams

4.1 Introduction

Tamarind is adapted to a wide range of ecological conditions, reflecting its wide geographical distribution in the sub and semi-arid tropics. It grows wild in many countries and is also widely cultivated. It thrives under the same conditions as the baobab tree (Jansen, 1981; Mahony, 1990), and often grows near villages though it is rarely found growing in close proximity to other species (FAO, 1988). 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).

4.2 Climate

Joshi (1985) has suggested that tamarind is a weather indicating plant of tribals in Rajasthan, India. When the length of the fruits appear longer than usual, weather with abundant rains conducive to the ripening of genhu (*Triticum aestivum* L.) and chinna (*Cicer arietinum* L.) is forecasted. This is a common phenomenon throughout the forest.

4.2.1 Water

Tamarind grows well with an evenly distributed mean annual rainfall of 500-1500 mm (FAO, 1988; Jama *et al.,* 1989; Hocking, 1993). The minimum rainfall requirement is 250 mm. In areas where rainfall is this low, for example in the Sahel, where annual rainfall is 300-400 mm, the trees are usually located near the water table or along water courses. The maximum annual rainfall which tamarind can tolerate is up to 4000 mm, provided that the soil is well-drained (Duke and Terrell, 1974). Tamarind grows under these conditions in the wet tropics but does not flower (Allen and Allen, 1981). In fact, dry weather is important for flower initiation and if heavy rains occur during flowering tamarind does not bear fruit. Thus, in the wet tropics of northwest India and south Malaysia, the trees grow well but do not produce any fruit (Morton, 1987). Dry weather is very important for fruit development and regardless of total annual rainfall, tamarind produces more fruit when subjected to a fairly long annual dry period (Allen and Allen, 1981; von Maydell, 1986). Tamarind can be grown in very dry areas with supplementary irrigation and can withstand up to six months without rainfall; this is due in part to its deep and extensive root system (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 the intermediate zone above 300 m, a few trees can be seen, but their bearing ability is comparatively less than those grown in the dry areas.

Tamarind is usually evergreen but may shed its leaves in very dry conditions during the hot/dry season (Morton, 1987).

4.2.2 Temperature

Essentially a tree of tropical climates, tamarind thrives under a maximum annual temperature ranging from 33-37° C to a minimum of 9.5-20° C. The trees are very sensitive to fire and frost and require protection when small (Troup, 1921; NAS, 1979). Older trees are more 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).

4.2.3 Light

Tamarind is a light demanding tree and grows very slowly. It is often isolated from other vegetation and the ground is usually bare around the tree due in part to the dense shading by the canopy.

4.2.4 Wind

The tamarind tree is very resistant to strong winds, and can tolerate violent typhoons and cyclones (von Maydell, 1986; von Carlowitz, 1986). Often known as the hurricane-resistant tree (NAS, 1979), it has strong and pliant branches and a deep and extensive root system, which anchors it to the ground (Coronel, 1986). Another explanation for the isolated growing habit of the tree is its tolerance to harsh environments.

4.2.5 Altitude

Tamarind has been reported to grow from altitudes of 0-2000 m (Roti-Michelozzi, 1957; Dale and Greenway, 1961; Brenan, 1967; FAO, 1988; Jama *et al.* 1989). The lack of tamarind growing at higher altitudes is associated more with the decrease in temperature than the altitude itself. In Yunan, China, Li *et al.* (2004) considered tamarind suited to 1400m when planting a range of trees for afforestation between 1400-1600m above sea level.

4.3 Soil Requirements

The tamarind tree can grow in a wide range of soils (Chaturvedi, 1985; Sozolnoki, 1985) and has been suggested by Sozolnoki (1985) and Galang (1955) to have no specific soil requirement. 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 (Anon, 1991). Older plants are more resistant to salinity than seedlings and have been found growing close to the sea (NAS, 1979; Pongskul *et al.,* 1988; Anon, 1991). In fact, in northeast Thailand, tamarind has been reported to establish naturally in areas with recently salinised soils (Nemoto *et al.,*1987). Dwivedi *et al.* (1996) concluded during pot experiments that tamarind could grow in soil containing up to 45% exchangeable sodium. El-Siddig *et al.*, (2004 a, 2004 b) investigated germination and seedling establishment in saline media and found a slight delay in emergence but no effect on seedling growth with up to 30 mM NaC1. Any detrimental effects with higher salt levels were mainly due to accumulated ions. Gebauer *et al.*, (2001) suggested that tamarind seedlings can tolerate salinity up to 80 mM NaCl as a result of their ability to avoid excess ion accumulation through increased leaf volumes associated with succulence.

However, tamarind, thrives best in loamy, deep, well drained alluvial soil, which favours the development of a long tap root (Galang, 1955). Silt-clay and clay soils were not condusive to plantations of tamarind in Mali (Kelly and Cuny, 2000) but red sandy loam soils in Andhra Pradesh, India were (Rao *et al.*, 2000).

The tree does not tolerate water-logging (Relwani, 1993; Vogt 1995). In Africa, the tree is reported to grow near ant-hills or termite mounds, which indicates its preference for well aerated soils (Dalziel, 1937; Eggeling and Dale, 1951; Irvine, 1961; Allen and Allen*,* 1981). The optimum pH for tamarind is 5.5-6.8, which is slightly acidic (FAO, 1988), though it also grows well in alkaline soils (Singh *et al*., 1997, quoted from Rao *et al.,* 1999). It has been suggested (Jansen, 1981) that its association with ant-hills and termite mounds may also be due to a preference for a slight lime content in the soil.

4.4 Tamarind as a component of vegetation

In Africa tamarind is typically a scattered tree of the savannah but it is intimately related to people and habitations which provide a degree of protection because of the uses made of the tree. Ethnobotanical and other surveys confirm this in Northern Cameroon (Tchiegang – Megueni *et al.*, 2001), North-east Nigeria (Lockett *et al.*, 2000), Benin (Codjia *et al.*, 2003), Burkino Faso (Kristersen and Lykke, 2003), Sudan (El – Siddig *et al.*, 1999), Southern Malawi (Maliro and Kwapata, 2002), Kenya (Muok *et al.*, 2000) and Madagascar (Bayala *et al.*, 2003). The role of the species as a component of agrosilvopastoral land use in Sahelian villages has been recorded (Slingerland and Kresson, 2001).

Little is known about tamarind as a component of secondary forest associations, its ability to regenerate naturally, nor whether there are distinct eco-geographical populations (see section 5.2.1.3). A survey of existing ecological community data for Africa in this respect could be helpful. Tesfaye *et al.*, (2001) described the vegetation of the Gambella Region of South-eastern Ethiopia and a characteristic tamarind plant association was affiliated to others of the Sudanian region. Gashaw *et al.* (2002) noted that periodic bush fires seemed to stimulate natural regeneration of tamarind. Deforestation has led to a degree of erosion of tamarind, for example in Malawi (Maliro and Kwapata, 2002).

In other parts of the world protection of the species by people is also apparent, for example, in the Ponchicherry region of South India it occurs in sacred groves (Ramanujam *et al.*, 2003); it is associated with villages in Orissa, India (Misra and Dash 2000) and in secondary forests in Sri Lanka and the Western Ghats, India, and Gujarat (Hitmayake and Ratnayoke, 2000; Sharma *et al.*, 1986; Champion, 1936); and in homestead gardens in Bangladesh (Ahmed and Rahman, 2004).

As a leguminous species the degree of nodulation could be a factor influencing failure to regenerate naturally although the genus seemed to survive as a non-nodulator in South Pakistan (Qadri and Zehra, 2004). Mycorrhizal associations may be equally important (see Chapter 5). Seedlings prefer soils with organic matter available for early growth (Aubreville, 1950), and Thiyageshwari *et al.* (2003) confirmed the need for nutrients during the nursery stage to raise sturdy tamarind plants for afforestation; root length appears to be critical in the early growth stages.

4.5 Pollen and seed dispersal

The presence of nectar in the tamarind flower suggests that pollination is carried out by insects (Prasad, 1963; FAO, 1988). 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. When the fruits are eaten fresh, the seeds are often discarded (Bettencourt *et al.*, 1999).

Chapter 5. Agronomy and Production areas

K. El-Siddig

5.1 Introduction

Tamarind is underutilised and therefore an underresearched species. Although widely grown traditionally, there is a limited amount of literature on its agronomic requirements. This chapter reviews the available information on best practices for its agronomy, from propagation through establishment to the management of trees in the field, including the occurrence and management of the main pests and diseases. Then the various types of production systems and areas are assessed.

5.2 Propagation

Tamarind is traditionally grown from seed, although vegetative and tissue culture propagation methods have been developed to capture the attributes of specific genotypes. The methods reviewed here indicate that propagation will not be a constraint to the production of quality planting material for those interested in establishing tamarind orchards. Neither will propagation be a problem for those plant breeders and scientists wishing to select elite cultivars or to breed improved ones.

5.2.1 Seed propagation

Propagation by seed is the least expensive means of propagation and can be used to produce a large number of new plants from a minimum of stock material. In addition, seed propagation is necessary in order to produce seedlings to be used as rootstocks onto which selected cultivars can be grafted. The main disadvantage of seed propagation is that seeds fail to produce plants true to type and also resulting seedlings take a longer time to produce productive plants than those produced through vegetative propagation. However, a proper understanding of the processes involved in seed germination and initial growth is an important prerequisite for the increased domestication and cultivation of tamarind.

5.2.1.1 Germination

Tamarind produces relatively large seeds that average 11-12.5 mm in diameter (Morton, 1987). They are flattish, shiny brown to blackish seeds, with a hard impermeable seed coat. The fleshy cotyledons make up most of the seeds' volume and weight, and serve as the sole food storage organs. Seeds average 1800 to 2600 per kg (Jøker, 2000).

Germination of tamarind seed is epigeal. The radicle swells and emerges from one end of the seed and descends rapidly. The hypocotyl elongates, arches slightly and raises the cotyledons and shoot apex above the ground towards the light. The testa falls to the ground when the cotyledons expand (Troup, 1921).

The seed storage behaviour of tamarind is orthodox (Riley, 1981 quoted by Hong *et al*., 1996) which means that they can be kept in good condition if attention is paid to the moisture content. Fresh seeds retain viability for at least six months when kept dry at ambient temperature. Seeds store well in dry sand, remaining viable for at least two years if kept in closed vessels for protection from insect pests (Teel, 1984; Morton 1987; Parrotta, 1990). When handling seeds therefore their viability can be maintained if the seeds are well-dried, mixed with sand and kept in air-tight containers. Reducing the temperature is also helpful in maintaining viability of dry seeds. Albrecht (1993 quoted by Hong *et al*. 1996) reported that seeds could be stored for several years in air-tight packs at 10^{o}C and 7-15% moisture content.

On average, tamarind seeds begin to germinate about 13 days after sowing (Padolina, 1931; Galang, 1955) but may take a month to complete (Jøker, 2000). It is recommended that up to 45 days from planting be allowed to ensure that maximum germination has been achieved (El-Siddig *et al.*, 2001). The germination pattern is similar to that of other leguminous species in which the hard seed coat interferes with water and oxygen uptake, thereby limiting germination. The germination capacity of fresh or well stored tamarind seed is reported to vary from 65-75%. Coronel (1991), stated that, depending on the conditions, germination might vary from 30 - 70%. In another study, 90% success was achieved (Teel, 1984). However, much depends on the degree of maturity of the seeds when harvested and their moisture content prior to testing the germination.

5.2.1.2 Seed treatments

Germination of tamarind seed can be accelerated by overcoming the hard seededness through acid or mechanical scarification and soaking in hot water.

Scarification with concentrated sulphuric acid has proved to be highly effective with tamarind seed. Muhammad and Amusa (2003) observed the highest germination percentage in seed lots treated with 50% sulphuric acid for 60 minutes. El-Siddig *et al*. (2001) reported that immersion of tamarind seeds in 97% sulphuric acid for at least 45 minutes at 25º C is an effective method for promoting fast and synchronous germination. Scarification with sulphuric acid at 200 ml kg^{-1} for 15 minutes increased seed germination to

67.2% and reduced the incidence of abnormal seedlings to 9.9% and left no hard seeds (Parameswari *et al.* 2001 a). In another study, Parameswari *et al.* (2001 b) reported that seed size and duration of acid scarification are positively related, where bigger sized seeds require 20 minutes of acid scarification while only 15 and 10 minutes respectively was needed for medium and small sized ones. In Burkina Faso, the seeds were scarified using 7% sulphuric acid washed and dried and then stored in sealed containers for 52 weeks at 4^{o} C. The germination percentages after 20, 28 and 52 weeks was satisfactory, but showed little improvement over untreated seed (Some *et al*., 1990).

MacDonald *et al*. (2002) showed that the highest germination percentage and subsequent growth development of tamarind seed occurred following pretreatment with methanol for 10 minutes. Seeds immersed in methanol, ethanol and sulphuric acid for 10 minutes produced seedlings with high vigour (Idu and Omonhinmin, 2001).

On the other hand, studies undertaken at the Malawi Forest Research Institute clearly indicate that seed pre-treatment is not required for the enhanced germination of tamarind seed (Muabamba and Sitaubi, 1995). Although no seed pre-treatments are essential, various pre-treatments can accelerate the speed of germination. Soaking in cold or tepid water for 24 - 48 hours has been reported to hasten germination (Troup, 1921; Von Carlowitz, 1986). In Malawi, seeds of tamarind thoroughly cleaned and soaked in water overnight to encourage germination resulted in more than 80% germination (Prins and Magehembe, 1994).

The hard seed coat of tamarind can also be softened by hot water treatment. Muhammad and Amusa (2003) found that soaking seeds in hot water may overcome seed coat dormancy and stimulate germination. The germination response of tamarind seed to hot water treatment increases with increasing temperature (up to 100^{o} C) and soaking period (up to 60 min).

Gashaw *et al*. (2002) reported that short exposure of seeds for one minute to high temperatures (200^{o}C) generally stimulated germination whereas prolonged exposure to these temperatures reduced seed germination, suggesting that frequent and light burning in wooded savanna grasslands seems to stimulate and enhance germination of tamarind seed.

Vanangamudi and Vanangamudi (2003) compared seven growth stimulants on seed germination and seedling growth of tamarind and found that three of them (IAA, succinic acid and KH_2PO_4) proved to be effective in enhancing the germination and seedling vigour. According to Sankaranarayan *et al.* (1994), seed germination can also be accelerated by soaking in 10% cow urine or cow dung solution (500 g in 10 l) for 24 hours, when germination more than doubled.

Mechanical scarification has also been effective in breaking the seed coat dormancy. Scratching the region near the hilum on coarse sand paper or nicking it with a knife increased the rate of germination (El-Siddig *et al.*, 2001). Scraping the seed coat by rubbing on a rough surface to facilitate quick absorption of water also increases the rate of germination (Gunasena, 1999). Masano (1994) found that slicing off the end of the seed resulted in increased germination.

Magehembe (1995) reported that seed germination could be enhanced by sowing immediately after extraction and/or cleaning. However, some studies (FAO, 1988) indicate that germination can be improved by storing the seed for six months before planting.

Tamarind seed can germinate in the presence of low salt concentrations. In a greenhouse experiment, the effect of 0, 30, 60 and 120 mM NaCl on seedling emergence and early growth of tamarind was investigated (El-Siddig *et al.*, 2004 a). Results have shown that percent emergence and seedling dry weight were not markedly affected by 30 mM NaCl, but progressively stronger inhibitory effects were observed at 60 and 120 mM. In another study, the effects of reduced water potential (0, -0.3, -0.6, -0.90 or -1.30 MPa) generated by either NaCl or polyethylene glycol-6000 (PEG) on water uptake and germination of tamarind seeds were investigated under laboratory conditions (El-Siddig, *et al.*, 2004 b). At each iso-osmotic solution, PEG appeared to be more inhibitory to water uptake than NaCl, especially at the lowest water potential (-1.2 MPa). At this water potential, no germination was observed in both NaCl and PEG solutions. For the other treatments, NaCl resulted in lower germination percentages than iso-osmotic solutions of PEG. These results suggest that the main effect of PEG occurred via an inhibition of water uptake, while the detrimental effects of NaCl may be attributed mainly to accumulated toxic ions.

It is important to clean seeds when they are collected. Seeds often become contaminated with fungi after collection and as a result tend to deteriorate if stored in this condition. Sometimes seeds become contaminated with pathogens whilst still in the pods on the trees. Seed borne pathogens can affect germination and subsequent growth. Seed dressing with carbendazim (Bavistin), dithane M-45 (Mancozeb), thyride (Thiram), copper oxychloride (Fytolan) and an organo-mercury fungicide (Ceresan at 3 g kg^{-1} of seed weight) have been recommended for control of seed borne fungi (Purohit *et al.*, 1996). However the use of these fungicides may be subject to local regulations.

5.2.1.3 Seed sowing

Under natural conditions the seed pods fall from the trees and the seeds are released following decomposition of the pods. These seeds germinate and result in natural regeneration if conditions are favourable. Germinated seedlings often survive under the parent trees where they become established if protected from grazing animals. Seeds transported by birds and other wildlife germinate readily under the shade of another tree, such as baobab and on termite mounds. In South India, monkeys are the major seed dispersing agent (Troup, 1921). See section 4.4.

Seed collection for propagation purposes involves selection of vigorous, disease-free mother trees of superior phenotypes from forests, pastures or farms. Seed viability and storage life are greatest if seeds are collected when mature. Fruits are collected only when they are fresh and ripe as indicated by a buff, brittle epicarp. Pods are shaken from the tree or if reachable fruit pedicels are clipped (Morton 1987).

The pods should either be dried in the sun and the seeds removed from the pulp by hand-kneading, or by soaking in water for several hours, which makes it easier to remove the seeds by rubbing the pulp though a screen. Washed seeds are then dried in the shade and stored in well-ventilated gunny bags, or paper bags, in a cool place.

A seed bed should be prepared for germinating the seed. Chattopadhyay and Mohanta (1988) reported that seed germination could be encouraged by using cow dung or cow dung and sand in the propagation medium. However, a normal nursery potting mixture containing three parts of top soil, one part of sand and one part of compost, can be successfully used for germinating tamarind seed.

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 both ways. The best germination results if the seeds are covered by 1.5 cm of loose sandy loam or a mixture of loam and sand. If the seeds are planted too deep seedling emergence is delayed and there may be some rotting due to poor aeration. Sowing seeds in an upright position with the micropylar end positioned upwards significantly improved germination and seedling vigour (Parameswari *et al.*, 2001 e). Seeds may be sown in polyethylene nursery bags provided the bags are deep enough to accommodate the tap root without causing undue distortion. Bag raised seedlings should be planted before they get root bound.

Adequate moisture is needed to ensure germination and seedling establishment is as uniform as possible.

Trials were carried out at the Institute of Forest Genetics and Tree Breeding, Coimbatore, India, to study the effect of ten different potting media and eight bio-fertiliser combinations on tamarind quality seedling production. Potting media in the ratios of i) Sand: spent mushroom beds (2:1), ii) Sand:

spent mushroom beds (1:1) and iii) Sand: Soil: Farm Yard Manure (1:2:1) were found to produce the best quality seedlings. The addition of bio-fertilisers was found not to have any effect on the growth of seedlings. The study on the effect of shade levels (4 levels) and container types and sizes (6 levels) revealed that shade nets with 25% shade level and 300 cc individual cell root trainers are best suited to establish nurseries for raising large numbers of tamarind seedlings.

Some research attention has been given to the improvement of germination through pelleting seeds to provide mycorrhizal fungi, but this is only cost effective in commercial operations (see 5.3.3).

Seedlings grow rapidly in the early stages and produce a long tap root which may reach 30 cm or more within two months of germination (Troup, 1921). Seedlings should attain a height of at least 80 cm before being transplanted to the field at the beginning of the rainy season. Under normal conditions seedlings are large enough to be planted in the field within a year. After planting in the field, seedlings should be protected from browsing animals.

Hegde (2000) has outlined the need for decentralised nursery management as the way to peoples' participation in social forestry, based on experiences in part raising tamarind for afforestation of marginal and waste lands.

5.2.2 Vegetative propagation

Vegetative propagation can be achieved by using any one of several methods. Furthermore, vegetative propagation is a rapid means of improving the quality of the produce to meet the varying demands of diverse commercial markets. Trees with exceptionally good fruit should be propagated vegetatively (von Maydell 1986).

Tamarind can be successfully propagated by root and stem cuttings or air- and stem-layering (Troup, 1921, Anon, 1976, von Maydell 1986, Morton 1987) or by budding and grafting.

5.2.2.1 Cuttings

Tamarind coppices well. When coppiced or young trees are damaged root suckers are produced. These can be removed and used for small scale propagation. However, the easiest and the cheapest method of vegetatively propagating tamarind is by stem cuttings. Although vegetative propagation through rooting of stem cuttings was reported to be unsuccessful by Mascarenhas *et al.* (1987), a number of other reports have claimed success. A technique using soft wood terminal cuttings has been developed, and the protocol standardised, by the Forest Research Station at Maddimadugu, Andra Pradesh, India (Srivasuki *et al.*, 1990). Cuttings of shoots bearing new flushes of fully turgid leaves are collected in the morning. They are immediately dipped for ten seconds in 1000 ppm of indole butyric acid (IBA), and in 50% isopropyl alcohol, before being planted in polypropylene tubes containing vermiculite/perlite (1:1) and placed in a mist propagator with 70-80% humidity. The use of the growth regulator IBA increased the rooting of cuttings to over 94% compared to the control, which recorded only 25%. Furthermore, the time taken to initiate rooting was only 10-15 days with IBA, while the control took 40-50 days. Terminal cuttings have an advantage over mid stem cuttings because there is only one cut end thus reducing the possibility of infection by disease causing organisms during or after the rooting phase.

Soft or semi-soft stem cuttings, 15-20 cm long, taken from 1-2 year old branches can also be rooted (Swaminath *et al*., 1990). In this method, the cuttings are wrapped in moist cloth after removal from the trees to prevent moisture loss. They are then dipped in a rooting hormone, preferably IBA at 1000 ppm, and placed in a sand bed in a mist chamber. Bud initiation and root formation occurs after about 20 days and new leaves are formed after about 45 days. Hard wood cuttings will not root and hence their use should not be attempted.

5.2.2.2 Budding and Grafting

Vegetative propagation by shield and patch budding, cleft grafting, whip grafting and approach grafting are reliable methods, although they are expensive and time consuming (Purushotham and Narasimharao, 1990).

Successful budding requires that the scion material has fully-formed, mature, dormant buds, and that the rootstock be in a condition of active growth such that the 'bark is slipping'. In tropical areas, the bark slips anytime the plant is in active growth - which is practically year-round. For patch budding, seedling rootstocks should be grown in raised beds and 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. Shield and patch budding and cleft grafting have been used for producing plants for large plantations in the Philippines and Thailand (see Plates 3-5).

Approach grafting is successful for difficult-to-graft species, even when others techniques fail, because both the scion (upper portion of the grafted pair) as well as the seedling root stock remain attached to their own root systems during the period of graft union formation. Approach grafting has been used in tamarind with up to 95% success (Swaminath and Ravindran, 1989; Daniel, 1998, personal communication).

The veneer grafting method possesses promise for mass scale commercial propagation. For conducting this grafting operation, rootstocks about six months old and of uniform size should be selected. The scions should be defoliated before grafting. Veneer grafts are made eight cm high on the root stock and immediately after inserting the scion the root stock is removed above the graft union. This method is reported to give about 50% success (Amin, 1978; Purushotham and Narasimharao, 1990).

For softwood grafting, the rootstock seedlings should be defoliated and their tops cut off at 15 cm high immediately before grafting. A vertical downward cut is made in the centre of the cut stem to about four cm depth and the scion sticks are cut into wedge shapes, inserted into the stock and wrapped using two cm wide 200 gauge polyethylene ribbon. Soft wood grafting has been shown to be the best grafting method in terms of successful unions and survival rates (Navaneetha *et al*., 1990) (see Plates 6,7).

Three grafting methods for propagating tamarind in the Coast of Colima, Mexico, splice side graft, wedge graft and bud graft, were evaluated (Gonzalez-Gonzalez *et al*., 2001). Rootstocks were from 8-month-old healthy plants 1 m tall and 1 cm in diameter, obtained from Criollo seedlings, and the scions were obtained from a healthy 15-year-old 'Criollo Veracruz' donor tree. This donor was selected for its excellent agronomic traits and fruit yield. Naturally defoliated, vigorous and terminal scions were disinfected with fungicide and used the same day that they were excised. Splice side grafting resulted in 79% success after 20 days.

In the sub-humid parts of India, experiments revealed that the time of grafting significantly influenced per cent sprouting, days to sprout, per cent graft success, and linear and radial growth (Awasthi and Shukla, 2003). Softwood grafting in April resulted in highest graft success (83%), maximum linear growth (56 cm), and maximum saleable plants (74%) in the following March. Similar results were obtained by Bharad *et al.* (1999) who found that March and April were the better months for grafting under the conditions in Akola, India. Under the conditions pertaining in Karnataka, India, the time required for grafts to take was longer during the winter months (October to December) than during other months (Reddy *et al*., 200). As the temperature increased, the time taken for graft union and sprouting decreased, with the least number of days (14) being observed in March. The graft take was better in pre-cured than uncured scions. The highest success percentage (100%) in cured scions was recorded during March, closely followed by February (94%).

Successful grafting techniques have been reported in Peru (Ramirez *et al*., 1986) where scions grafted on to wild, criollo rootstocks of 0.66-0.75 cm diameter were the best. The success achieved for splice grafting and whip and tongue grafting was 65.3% and 61.3%, respectively. Shield budding was much less successful.

The correct spacing of mother plants is important to produce shoots for commercial production of grafted plants. Feungchan *et al*. (1996 a) reported that a spacing of 2 x 2 m is the most suitable for multiplication purposes. The age of the rootstocks for soft wood grafting is also important for success. Scions pre-conditioned for 30 days prior to grafting on to 6- and 9-month-old rootstocks growing in the green house resulted in 69-72% success at 60 days. Grafting success has been attributed to the fact that rootstocks of this age contain a higher proportion of reducing sugars to total sugars than at other ages (Kulwall, 1997, quoted in Rao *et al*., 1999; Satisha *et al*., 1997).

Tamarind provenances differ in their graft success (Sathishkumar and Mokashi, 2003). Provenance may also influence traits such as hardiness, growth rate and adaptability to climatic conditions, and this should be kept in mind when purchasing or collecting scion materials from different locations.

Root stock selection for vegetative propagation of tamarind is important as it controls the vigour and the equilibrium between yield and quality. Dwarfing rootstocks are considered best because they result in short trees, which are easy to manipulate for management practices, have increased fruit production, and require less land and labour inputs. In Thailand, a dwarf rootstock has been identified based on morphological characteristics, such as internode length and leaf area. These characters were correlated with the number of stomata on the leaves. Attempts to reduce canopy size by intergeneric grafting tamarind scions on to root stocks of other leguminous species have not been successful. The application of growth inhibiting chemicals has also had no dwarfing effect (Feungchan *et al*., 1996 b).

5.2.2.3 Layering

Layering is a simple and easy method of rooting a branch of a shrub or tree while it is still attached to the parent plant. It is a widely practised propagation method for tamarind. In ground layering, a flexible branch is bent down and pegged to the ground, and the point of contact covered with soil. A small cut is made in the lower side of the stem where it touches the ground to impede sap circulation and encourage rooting. After 3-6 weeks roots form at the point of contact with the soil and a new plant can be obtained by severing the branch above the place of rooting.

For air layering or marcotting, a branch is selected and a 2.5 cm lenght of the bark is removed. This area is covered with a moist soil mixture or a moist porous material, such as coir fibre dust, and kept in position by wrapping with polyethylene film. It is kept moist for 2-3 months. When large quantities of roots are observed through the polyethylene film, the branch with its roots is severed from the parent tree and potted up for later planting (see Plates 8,9).

The girdling of etiolated shoots reportedly stimulates air-layered roots to be produced within 10 weeks, and the process can be further accelerated by several weeks through the application of the growth regulator indolebutyric acid (IBA) (Troup, 1921). Girdling and etiolation increases the percentage of total sugars, reducing and non-reducing sugars, lowers the starch content and raises the percentages of soluble and total nitrogen. This results in a lower C:N ratio, a higher level of the rooting cofactor and lower levels of indigenous inhibitors compared with nongirdled etiolated shoots. The application of IBA or IBA + NAA (naphthalene acetic acid) increases the number and the length of air-layered roots, and reduces the time for rooting from about 10-6 weeks (Gowda, 1983). Navaneetha *et al*. (1991) reported that shoots etiolated for one month before treatment in May with IBA at 1000 ppm gave 75% rooting and resulted in the highest subsequent survival. No rooting was observed when the treatment was done between January and March. This demonstrates the importance of marcotting only when the parent trees are in an optimal physiological condition. In another experiment IBA/NAA each at 1000 ppm, resulted in only 63% rooting.

5.2.2.4 Micro-propagation

Tamarind may be propagated by tissue culture techniques; however, reports on *in vitro* morphogenesis in this species are limited, due to its recalcitrant and callogenic nature (Hazara *et al*., 2004). To overcome these limitations, an attempt was made to induce meristematic activity in seedling explants. Seedlings were germinated in media with or without thidiazuron (TDZ). Presence of this growth regulator restricted the differentiation of the apical meristem to form shoots. It triggered proliferation of the meristematic tissue at the cotyledonary node and a large number of meristematic buds appeared in a radial pattern around the node. The meristematic activity extended to the junction of the epicotyl and hypocotyl, giving rise to buds in the form of protuberances from all sides of the junction. These buds differentiated to form shoot primordia and subsequently to shoots in a growth medium devoid of growth regulators. Plants developed by micrografting of these shoots on seedling-derived rootstocks survived in soil.

Shoot tips, cotyledons and cotyledonary nodes have been used successfully as explants for tamarind tissue culture (Splittstoesser and Mohamed, 1991). The explants were cultured in an MS (Murashige and Skoog, 1962) medium supplemented with TDZ (thidiazuron) / IBA (indole butyric acid) or BA (butyric acid) / NAA (naphthalene-acetic acid) and incubated at 28 ^{o}C for 5 weeks under an 18 hour photoperiod. The shoot tips of tamarind regenerated only one shoot while the cotyledonary nodes produced multiple shoots. Multiple shoots were however induced on shoot tips and nodal explants on an MS basal medium supplemented with BAP (Benzylaminopurine) (5×10^{-6} M). All shoots were rooted on MS with IAA (indole acetic acid) (5×10^{-6} M) and the micro-propagated plants were successfully transferred to the soil (Jaiwal and Gulati, 1992). Shoot tips from *in vitro* grown seedlings have been regenerated into plantlets on MS medium containing IBA or IAA. Higher concentrations of growth hormones (2 and 5 mg/l) induced better rooting, but a media supplemented only with coconut water or BAP supported growth of shoots but not that of roots (Kopp and Nadaraja, 1990). Ganga and Balakrishnamoorthy (1997 b, cited in Rao *et al.*, 1999) worked out the optimum *in vitro* culture conditions for high frequency plant regeneration from seedling stem explants of the 'Urigam' tamarind cultivar. The MS medium supplemented with 2.5 mg/l BA, and 0.5 mg/l GA (gibberellic acid) provided the earliest response to shoot bud differentiation and the greatest number of multiple shoots per culture. Induction of multiple shoots from axilliary buds and *in vitro* rhizogenesis of these microshoots has also been reported (Balakrishnamoorthy and Ganga, 1997 a, 1997 b, cited in Rao *et al.*, 1999). Response to axilliary bud proliferation was on the MS medium plus BA and GA, while the greatest rhizogenic response was on the MS medium at half strength plus 0.5 mg/l each of IAA and IBA. Tissue culture raised plants have been reported to show better growth in height, branching habit, spread of branches, and an early flowering and fruiting cycle, with the start of flowering at an average height of 3.7 m. This compares with seedling raised plants which flowered when the seedlings had reached an average height of 8.0 m (Mishra, 1997, cited in Rao *et al*., 1999).

Cotyledonary node explants of tamarind directly developed multiple shoots on MS supplemented with cytokinins, BA, kinetin or DAP (6-gamma-gamma-diemthylallylaminopurine) (Sonia *et al*. 2000). The regenerated shoots were further multiplied by culturing their nodal segments on an MS medium containing $5x10^{-6}$ M BA. The shoots were rooted on MS medium containing $5x10^{-6}$ M indoleacetic acid +0.2% of activated charcoal and the resulting plantlets were successfully established in soil in pots.

A protocol for *in vitro* regeneration of plants via adventitious bud formation from the mature embryo axis of tamarind was standardised (Mehta, *et al*, 2000). Explants consisting of a longitudinal section of embryo axis with attached cotyledon were cultured on MS medium with various combinations and concentrations of NAA, BAP and sucrose. Induction of adventitious shoot buds was achieved in the cut surface of the axis when cultured in a medium containing 2.69 muM NAA, 44.39 muM BAP and 4% sucrose. A medium consisting of 0.91 muM zeatin, 2.22 muM BAP, 0.41 muM calcium pantothenate and 0.40 muM biotin supported the differentiation of the buds to form elongated shoots. The shoots developed roots in a half strength MS medium with 2% sucrose following a 72 h treatment with auxin mixture in the dark. There was successful transfer to soil.

The *in vitro* propagation of tamarind was influenced by the season in which explants were collected (Prabakaran *et al*., 2003). The *in vitro* cultured explants collected in June showed the lowest contamination percentage (7.3%) and the highest survival percentage (92.6%), bud break percentage

(84.1%), mean number of multiple shoots per bud (1.3) and mean length of multiple shoots (3.4 cm). The shortest time to bud break was also observed in June-collected explants.

Although these micro-propagation techniques have shown promise, none of them has reached the stage of commercialisation. As with any other technology, the success of tissue culture as an effective tool in the large-scale multiplication and propagation of selected tamarind cultivars will be determined by economic factors.

5.3 Field establishment

Tamarind may be grown within various cropping systems. The trees may be grown as an orchard crop in a pure stand, as an agroforestry species in mixed cropping systems including home gardens, or as a hedgerow tree. In each of these systems, there are several methods available for establishing the trees.

5.3.1 Direct seeding

Tamarind can be established in the field by directly sowing seed (Chaturvedi, 1985). Seeds may be sown directly to establish plantations, hedgerows, or home gardens. On suitable sites, direct seeding of tamarind may indeed be a more economical method of establishment, as it eliminates the cost of growing seedlings in the nursery and is less time-consuming than planting seedlings. Furthermore, one of the primary advantages of seed planting versus seedling planting is that the germinating seedling has an undisturbed root system and does not suffer from transplant shock.

Once the site is properly prepared, seeds should be planted as soon after collection as possible to minimise loss of viability. However, seed which has been stored under optimal conditions (5.2.1.1.) may be used.The size of the planting hole is of little importance, but firm seed-to-soil contact and coverage is required for adequate germination. Planting holes should have been previously prepared and filled with well-decomposed manure or compost. The seed should be planted no deeper than 1.5 cm. For planting on the square, on the triangle, or in lines for orchard establishment, a few seeds are dibbled in 5 cm apart at each planting station. Planting stations should be approximately 4-5 m apart. The seeds, may also be sown at random in discrete patches, at 4-5 m apart. This method is practised in the Indian states of Tamil Nadu and Andhra Pradesh. After germination, and when the seedlings reach a height of 10-20 cm, they should be thinned to one at each planting point, the best seedlings being selected.

5.3.2 Transplanting

Transplanting nursery grown plants into the field can have advantages over direct seeding as the plants are already established. However, most newly planted trees are subject to ‘transplant shock’, which may result in increased vulnerability to drought, insects, diseases and other problems. To a greater or lesser degree, transplant shock lasts until the natural balance between the root system and the top or crown of the transplanted tree is restored. The chance of survival can be significantly improved by using practices which favour the development of the root system. Regular care during the first 2-3 years following transplanting is thus very important.

In order to provide space and an ideal medium for the development of a vigorous and deep tap root system planting should be done in 1 x 1 x 1m pits filled with well rotted organic manure at the time of planting.

Nursery grown seedlings or vegetatively propagated plants can be raised in nursery beds and delivered to the field as bare rooted plants. Alternatively they can be grown in, or transplanted into, polyethylene bags and taken to the field as container grown plants. Nursery-grown trees are usually transplanted during the early rainy season. If kept until the second rainy season, the plants must be cut back and the tap root trimmed.

A technique for raising large quantities of planting stock for use in roadside plantings has been described by Swaminath (1988). In this method, nursery seedlings are pricked out and transplanted into 12 m x 0.6 m x 0.6 m trenches dug two months beforehand. The trenches are filled with silt to 10-15 cm from the top. The seedlings are planted 60 cm apart and watered daily by flooding the trenches. After three months, the watering is reduced to once every three days, and for the following three months, to only once a week. The trenches are kept weed free and all side shoots are removed to induce apical dominance. After about seven months, when the height is about three metres and girth 6-8 cm, watering is stopped and the seedlings are dug up with a ball of intact earth. They are then tied with paddy straw and kept in a nursery and watered until they have recovered from the uprooting shock. When a new flush of leaves appears, they are ready for transplanting to their permanent roadside positions.

Nursery produced plants can be transplanted to the field at about 12-14 months, by which time they are about 80 cm tall. Under optimum growing conditions they may achieve this height in 4-6 months. In India, seedlings ranging from 0.4-2 m in height are commonly planted (Jambulingam and Fernandes, 1986). If growth is poor, the seedlings should be retained in the nursery for another year. However, it is difficult to handle these older seedlings as their tap roots may have penetrated deep into the soil, in which case they will require root pruning and care should be exercised in transporting them. Overgrown seedlings can be more effectively transplanted as stumped seedlings, with stem and tap root pruned to lengths of about 5 cm and 20-25 cm, respectively (Troup, 1921).

When seedlings or grafted plants are transplanted in the field their size may range from 0.4-2.0 m tall. In some districts of Tamil Nadu, seedlings are encouraged to grow up to 2 m tall by applying manure and removing axillary buds. As these field planted seedlings can be tall and lanky, they should be staked for at least a year, or until they can support themselves. The planting holes should be well prepared and be at least 30-50 cm^3 in size.

5.3.3 Field spacing

The spacing between plants may range from 5-13 m apart. Spacing may be even wider on fertile soils where the trees grow larger. When establishing a pure stand plantation, the final spacing should be at least 13 x 13 m square or on the triangle. Inter-cropping of young trees with a range of annual crops is possible at this spacing There can be an advantage in planting at higher density (4 x 4 m or 5 x 5 m), followed by thinning two or three times to the appropriate final spacing of 8-15 x 8-15 m. This allows some further selection in the field and reduces the weeding costs in the early years. In parts of India tamarind is established at 8 x 8 m, 8 x 12 m or 12 x 12 m (Jambulingam and Fernandes, 1986).

The final spacing can be closer when vegetatively propagated plants are used, as they do not attain the height or spread of seed propagated trees, and their management is easier. A few promising early-bearing varieties with high yield potential and attractive fruit qualities are now available for the growers in India. Some of the most popular cultivars in the south are 'PKM-1', 'Pradishtan', and 'Origam'. Grafted plants of these cultivars are being grown in Tamil Nadu either as isolated trees or in commercially viable groves in dry tracts. A spacing of 10 x 5 m has been recommended for commercial planting, and about 250 trees will be enough to cover a hectare.

In Central, Eastern and North-eastern Thailand, the recommended tree to tree spacing in sweet tamarind orchards is 10-12 m (Yaacob and Subhadrabandu, 1995). In the Philippines, the spacing recommended for seedlings is 16-18 m and for vegetatively propagated plants 8-10 m. In Sri Lanka, unproductive scrub forest lands have been successfully planted with tamarind by the Janata Estate Development Board at a spacing of 3 x 3 m in lines (Rodrigo, 1992).

Tamarind is frequently planted along land borders, canal banks, on field boundaries, in village groves, or in home gardens as individual trees.

In India, tamarind is used to make firebreaks, as the soil beneath is almost bare. When creating firebreaks, the spacing adopted is 2.5 x 2.5 m or 3 x 3 m. If the spacing appears to be too close some plants can be removed later. In Mysore, where tamarind is used commonly in fire lines, seedlings are raised in clay pots and planted in the field at a spacing of 3 x 3 m in 1 m^3 pits. Aftercare is minimal for these plantings, the only requirement being to hoe the soil around the plants once a year to remove any weed growth (Troup, 1921).

5.3.4 Time of planting

In seasonally dry regions, the best time for field planting is at the beginning of the rainy season, as soon as there is sufficient moisture in the soil. This will reduce the need for frequent watering until the plants are firmly established in the soil. In the initial stages of growth the plants may need some watering, especially during the hot summer months.

If irrigation is available, field establishment may be undertaken at any time of the year, even in the dry season. However, it is advisable to provide partial shade to the newly established plants if planting is carried out during the dry periods.

Seedling growth in the field is initially fast (about 1.2 m in the first two years) but slows later. Mean plant height increases by about 60 cm annually. Average annual growth has been reported as 50-80 cm (Streets, 1962; NAS, 1979; CATIE, 1986). However, when bare rooted seedlings are transplanted initial growth may be severely checked. This can be overcome by removing some of the leaves and irrigating frequently. If, due to unforeseen circumstances, planting in the rainy season is delayed the seedlings should be cut back and the tap root trimmed. In the Philippines the planting time is from May to June, and in Sri Lanka from April to June, but preferably from October to December to coincide with the onset of the main rainy season (Gunasena, 1997). Transplanted trees should be protected from cattle and other animals. Regular weeding around the plants is also essential for early establishment and good growth.

5.4 Husbandry

In its wild state, tamarinds establish through natural regeneration of seeds, grow slowly without any addition of fertilisers, start bearing fruits after a long period and produce fruits usually of inferior quality. Major constraints to the development and promotion of tamarind include low yielding and poor quality planting stock, lack of production technologies and lack of knowledge on nutrition management of the trees. Nevertheless, in recent years tamarind has attracted considerable attention from research and development agencies in many countries. In the following section, a number of aspects of tree management are dealt with, all of which are important to the success of tamarind cultivation.

5.4.1 Pruning and training

Initial training and pruning of young plants during the first years is essential for the development of well-formed trees. Tamarind is a compact tree and produces symmetrical branches. Young trees should be pruned to allow 3-5 well-spaced branches to develop into the main scaffold structure of the tree. In the Philippines, young trees are pruned in the early stages of growth to train 2-3 lead branches and to remove the very low branches, thus developing a desirable frame. Bearing trees require very little pruning other than maintenance pruning to remove dead, weak and diseased branches and water sprouts (Salim *et al.*, 1998). In closely planted orchards regular pruning is needed to rejuvenate fruiting wood and control the size of the trees.

5.4.2 Intercropping

Tamarind allows intercropping with a variety of annual crops. Vegetables and legumes can be grown during the rainy season in the interspaces in the first three to six years to augment farm income and improve soil fertility. Once fully established, the trees will provide a regular income to the grower even when other annual crops fail at times of protracted drought. The intercropping period is usually limited to four years for vegetatively propagated trees. In Thailand's central delta, intensive cropping is practised in the plantations of the sweet cultivars, which are always vegetatively propagated and transplanted. Intercropping can be extended up to even 8-10 years for the slower maturing seedling propagated plantations.

In Central America, Mexico and Brazil where there are more than 4000 hectares of well maintained tamarind orchards, intercropping is practised in the early stages. Intercrops, and where they are not used, cover crops, are useful to control competition from weeds and to conserve moisture. Intercrops should be fertilised in their own right, to reduce competition for nutrients and to maximise their yield. There is a wide choice of intercrops which can be grown depending on the soil, climate and local market demand.

5.4.3 Nutrition

5.4.3.1 Fertilisers and manures

The nutritional requirement of tamarind has not yet been studied and standardised recommendations are therefore not available. Trees are known to fruit well even without fertiliser application, due to their deep and extensive root system. In experimental plots in India, 25 g urea and 25 g single super phosphate per plant have been used, although response of tamarind to fertiliser application is reported as poor (Gupta and Mohan, 1990). In India, inorganic fertilisers are not normally applied to tamarind trees, but 5 kg of farmyard manure is applied to the planting hole at the time of planting. Every year thereafter 5 kg of farmyard manure and 5 kg of neem cake are applied per tree in the months of March and April. The commercial sweet tamarind growers in Thailand use inorganic fertilisers, mostly urea at 100-200 g/tree, which supports high yields. In the Philippines, the general recommendation is to apply 100-200 g/tree of ammonium sulphate, about a month after planting and an equal amount at the end of the rainy season. The amount of fertiliser is gradually increased as the trees grow. When the tree begins to bear fruits, about 500g of a complete fertiliser containing high amounts of nitrogen and potassium is applied per tree twice a year. A full bearing tree should receive 2-3 kg of an NPK complete fertiliser each year, the formula depending upon the nutrient content of the soil (Gunasena and Hughes, 2000).

Ilango and Vijayalakshmi (2002) reported that foliar spray of Cycocel (1500 ppm), Ethrel (500 ppm), Triacontanol (20 ml $tree^{-1}$), IBA (150 ppm), Planofix (100 ppm), micronutrient mixture (0.5%), $ZnSO_4$ (0.5%) + boric acid (0.3%) + $FeSO_4$ (0.5%) and Urea (1.5%) significantly improved flowering, pod set and retention, yield and quality attributes of tamarind compared to non-sprayed trees. Treatment with foliar feeding urea resulted in maximum number of flowering (76%), with Cycocel resulted in maximum pod set (32%) and retention (55%) per unit area, and with Triacontanol (20 ml $tree^{-1}$) resulted in maximum pod yield (8.3 kg $tree^{-1}$).

Fertilisation during the nursery stage is recommended to produce healthy plants for afforestation programmes (Thiyageshwari *et al.* 2003). Among the treatments, 0.6 g urea, 2 g single superphosphate and 0.6 of muriate of potash with 5 g of compost and 0.5 g of phosphobacteria recorded significant increase in shoot length (48 cm), root length (39 cm) and dry weight (11.2 g).

5.4.3.2 Nitrogen fixation

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. Tamarind was initially considered to be a non-nodulating species (Allen and Allen, 1981). However, some evidence suggests that it does form a symbiotic association with *Rhizobium* bacteria (Postgate, 1979; Athar and Mahmood, 1982; Quiniones, 1983) enabling the tree to fix atmospheric nitrogen under appropriate conditions (Quiniones, 1983; Ding *et al*., 1986). Root nodules collected from tamarind trees grown in plantations on acidic soils in Guangdong Province, China, described as elliptical or circular and light yellow in colour, have been reported to contain high nitrogenase activity (Quiniones, 1983). Rhizobial isolates from the Philippines have been described as gram negative, with short and long rods (Quiniones, 1983). In the semi-arid region of Nigeria, tamarind has been recognised as a potential nitrogen fixing tree (Okoro *et al*., 1986).

In Thailand, Towprayoon *et al*. (1996) and Chiemsombat *et al*. (1996) reported negative results following inoculation with *Rhizobium* as there was no indication of nodule formation or the association of the *Rhizobium* with the tamarind roots. Also in Pakistan, Qadri and Zehra, (2004) reported that the roots of tamarind do not develop nodule-like structures and have no bacteria or *Rhizobium* association commonly observed in other leguminous plants. The acetylene reduction assay for nitrogen-fixing activity was unable to demonstrate any symbiotic nitrogen fixation in tamarind roots and nitrogen-fixing bacteria were absent in the roots. The most outstanding feature noted in the roots were finger-like projections called 'microvilli,' whose function is unknown, but it has been suggested that they assist in water absorption. Detailed information on the root structure of tamarind is limited.

Yoneyama *et al*. (1993) studied the natural abundance of 15 N (delta 15 N) in leaves harvested from tropical legumes in Brazil and Thailand. The 15 N values were lower in *Sesbania grandiflora, Leucaena leucocephala* and *Casuarina* species pointing to a major contribution from N-fixation, while those of tamarind had high delta 15 N values. Many of the above studies have proved inconclusive. The ability of tamarind to fix atmospheric N deserves further investigation. If specific rhizobia could be identified, they could be used to enhance nitrogen nutrition and thus increase the growth rate of this species.

Ilango *et al.* (2000) carried out a series of experiments to test the effects of microbial nodulants, *Rhizobium* ALM2, 108cells/g and *Pseudomodules striata* PBZ, 109 cells/g on growth, biomass production and nutrient uptake in tamarind at the nursery stage. The combined preparation clearly increased root and shoot length and total leaf area compared to no modulation. There was thought to be a symbiosis between the micro-organisms that helped the availability and uptake of nutrients.

5.4.3.3 Mycorrhizal associations

Tamarind seedlings inoculated with 13 arbuscular mycorrhizal fungi (AMF) from various sources around the world have been demonstrated to exhibit increased leaf number, plant height, stem girth, biomass, phosphate and zinc content. The number of VAM spores in the soil, percentage root colonisation and external hyphae measured by soil aggregation were also higher. Tamarind responded best to inoculation with *Gigaspora margarita*, *Glomus fasciculatum* and *Pisolithus tinctorius* (Reena and Bagyaraj, 1990; Trate and

SriVaseeki, 2001). Maksoud *et al.* (1994), also observed significant increases in growth parameters and leaf P and K contents when tamarind seedlings were planted in pots inoculated with VAM and uptake of P and N is enhanced (Trate and SriVaseeki, 2001). The occurrence of VAM in soils varies (Gurumurthy and Sreeivasa, 2000; Ishii, 2000) and there may be the need to inoculate artificially. Inoculating tamarind seed with mycorrhizal inoculations of *Glomus fasciculatum* and *Pisolithus tinctorius* stimulated plant growth and P and N uptake compared to their non-mycorrhizal (NM) plants both under water stress and non-stress regimes (Vijaya and Srivasuki, 2001).

Guissou *et al.* (2001) studied the effects of inoculation with an AM fungus, *Glomus aggregatum* on water stress tolerance of four fruit trees including *T. indica* L. in a P-deficient soil (2.18 mug/g P-Bray I). Results showed that *G. aggregatum* stimulated growth and mineral nutrition of fruit trees but did not improve their stress tolerance.

Container grown seedlings of several leguminous species including tamarind were inoculated with three arbuscular mycorrhizal fungi (AMF): *Glomus faciculatum, G. mosseae* and *Gigaspora margarita*. Mycorrhizal fungi colonised differentially on the tree species tested and the overall growth responses were best for the legumes other than tamarind (Selvaraj *et al.*, 1996). The response to AM appears be much reduced when compared with other species of legume.

Functional compatibility between 13 tropical fruit trees - including tamarind - and two arbuscular mycorrhizal fungi (AMF) *G. aggregatum* and *G. intraradices* was investigated (Ba *et al*. 2000). Marked differences were found between them in terms of mycorrhizal formation, root colonisation, relative mycorrhizal dependency (RMD) and phosphorus concentrations in shoot tissues. Five of them showed dependency by a positive interaction with *G. aggregatum*, the most effective AMF. Tamarind was highly dependent (50-75% RMD). Phosphorus absorption probably contributed to this dependency more than the absorption of potassium. These results indicate that some tropical fruit trees do derive benefits from AM inoculation, while others do not.

Application of inoculums to the pits before transplanting the seedlings would therefore be an effective method of introduction of the VAM fungus. Parameswari *et al.* (2001 d) found that pelleting tamarind seed with Azospirillum @ 50 g kg^{-1} and inoculating with VAM @ 5 g $polypot^{-1}$ improved the seed germination and growth characters up to three months and aided in elite seedling production of tamarind.

5.4.3.4 Irrigation

Irrigation is not normally practised in tamarind cultivation, but promotes better growth during establishment and the early stages of growth, especially during the dry seasons (Yaacob and Subhadrabhandu, 1995). Where irrigation facilities are available watering should be done and repeated as the need arises in the early stages of growth. In later years as the deep tap root system develops, the need for watering becomes less. Flowering and fruiting is promoted by irrigation. In dry areas the use of water harvesting techniques during the rainy season should be considered as it encourages subsequent growth and fruiting (Chundawat, 1990). Mulching during the dry season will also help to reduce water losses from evaporation. Mulches around the trees also help in weed control and water conservation

5.4.4 Diseases and Pests

5.4.4.1 Diseases

Several diseases have been reported to infect tamarind in India, including various tree rots and bacterial leaf spots. The major diseases reported are leaf spots *(Bartalinia robillardoides* Tassi., *Exosporium tamarindi* Syd., *Hendersonia tamarindi* Syd., *Pestalotia poonensis* V Rao., *Phyllosticta tamarindicola* V Rao., *P. tamarindina* Chandra and Tandon., *Prathigada tamarindi* Muthappa, *Xanthomonas tamarindi* Cook, *Sphaceloma* spp. and *Stigmina tamarindi* (Syd.) Munjal and Kulshreshta, powdery mildew (*Erysiphe polygoni* DC. and *Oidium* spp.), a sooty mould (*Meliola tamarindi* Syd.), stem disease (*Fracchiaea indica* Talde.), white root and wood rot *(Ganoderma lucidum* (Leyss) Karst and Lenzites palisoti Fr.), stem rot *(Pholiota gollani* P.Henn), trunk and root rot (*Stereum nitidulum* Berk.), collar rot *(Phytophthora nicotianae* var. *Nicotianae)*; (Siddaramiah *et al.*, 1980), stem canker *(Hypoxlon nectrioides* Speg) and a bark parasite (*Myriangium tamarindi* Tendulkar) (Mukherji and Bhasin 1986; Siddaramaiah and Kulkarni, 1982; Morton, 1987; Parrotta, 1990). In Karnataka State, India, stony fruit disease caused by the fungal pathogen *Pestalotia macrotricha* Syd. (Lokesha and Shetty, 1991) makes the fruits hard and stony with fibrous structures. In general, sap rot and white rot, which might be caused by several diverse fungi, are the major diseases.

A mildew caused by *Oidium* sp. is a common occurrence in nursery seedlings. The disease causes defoliation and early growth is severely retarded. In Uttar Pradesh, India, tamarind has been attacked by *Cercospora* leaf disease resulting in severe defoliation. The causal agent is a form of *C. tamarindi* (Khan *et al*., 1988). In order to have effective control 3-4 sprays of wettable sulphur at 15 day intervals is the most economical method (Siddaramaiah and Kulkarni, 1982). They could also be easily controlled by spraying Maneb 80 wp, Benzyl 50 wp or Captan 80 wp at 200 ml of water, but note that the use of these pesticides may be governed by local legislation.

A seedling blight disease caused by *Macrophomina phaseolina* and *Rhizoctonia solani* is also important during the nursery stage. A significant reduction in blight incidence was achieved by raising seedlings in soils amended with sawdust or rice husk (Muhammad *et al.*, 2001). Increasing the number of days between amendment application and planting further reduces the incidence of seedling blight. The number of compound leaves and plant height were significantly increased in seedlings produced from seeds sown at 20 days after the application of soil amendment.

5.4.4.2 Pests

Tamarind trees are liable to be attacked by a large number of insect pests although in general it is not harmed by many of them except in plantations. In India alone, over 50 insect pests have been recorded as attacking tamarind, causing severe economic losses (Joseph and Oommen, 1960, Senguttavan, 2000). The major pests which attack tamarind include shothole borers, toy beetles, leaf feeding caterpillars, bagworms, mealy bugs and scale insects (Coronel, 1991). Among the worst are the sapsuckers, which affect the tender shoots and fresh foliage. The most destructive among these are white flies, thrips, coccids and aphids. The defoliators, which include caterpillars and the chafer beetles can also cause considerable damage. Some of these insects attack the flower buds and the developing fruits and seeds, while others damage the fruits during storage.

Some of the most serious pests in India are the hard scale insects (*Aonidiella orientalis* Newst., *Aspidiotus destructor* Sign. and *Saisetia oleae* Ol.) (Timyan, 1996). The oriental yellow scale (*Aonidiella orientalis* Newst.) (Hemiptera: Diadpididae), is a polyphagus pest which attacks tamarind. The eggs are laid under a protective covering such as cracks in the bark of the trees. After hatching, the nymphs crawl in search of suitable succulent parts of the plant. The scale insects can be controlled by removing the affected parts in the initial stages. When the infestation is serious, the careful use of chemical spraying is required; pesticides such as Diazinon or Carbosulphan at 0.1% solution provide effective control (Butani, 1979). For more information on the legal restrictions of these products the reader is requested to see http://www.pesticideinfo.org/Detail_ChemUse.jsp?Rec_Id=PC35079.

Mealy bugs (*Nipaecoccus viridis* Newst. and *Planococcus lilacinus* Ckll.) (Hemiptera: Pseudococcidae) 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. *Planococcus lilacinus* also attacks the roots. The leaflets become chlorotic and defoliation is common. Immature fruit fall is sometimes observed. Mealy bugs can be controlled by mechanical removal of infected shoots on a small scale. In serious infestations, chemicals such as Diazinon or Carbosulphan at 1% solution can, subject to local regulation, be sprayed. *Planoccus lilacinus* populations living in the soil can be displaced by raking or be killed using

5% Aldrin, where permitted, at 500 g per tree (Butani, 1979). For more detialed information on legal restrictions of this chemical refer to: http://www.pesticideinfo.org/Detail_ChemUse.jsp?Rec_Id=PC35039 Aldrin

Some thrips are reported to attack tamarind flowers. *Scirtothrips dorsalis* Hood (Thysonoptera: Thripidae) is a polyphagus thrip and the adults live for 10-15 days and complete 25 overlapping generations per year (Raizada, 1965). *Ramaswamiahiella subnudula* is another small yellowish thrip which attacks tamarind. *Halothrips ceylonicus* Schmutz (Thysanoptera: Phlaeothripidae) is a minor pest of tamarind. Thrips can be controlled by spraying with dimethioate, where permitted, at 20-30 ml /10 litres of water or Fenthion at 10-15 ml /10 litres of water (Wijegunasekera, 1999, personal communication).

The moth*,* *Eublemma ungulifera* Moore (Lepidoptera: Noctuidae) attacks flowers, weakening them, causing them to dry and fall from the trees. The larvae of *Cydia (Laspeyresia) palamedes* Meyrick (Lepidoptera: Torticidae) also bore into tender buds. The caterpillars cover the flowers and buds with webs and heavy losses of the crop may result. The slug caterpillar, *Latoia lepila (Parusa lepides)* can be a serious pest (Babu *et al*. 2000).

Other minor pests in India include the bruchid beetle, *Pachymerus (Coryoborus) gonogra* (Coleoptera: Bruchidae), which is the most serious pest of tamarind in India and Pakistan (Beeson, 1941; Mathur and Singh, 1961; Butani, 1978; Chaturvedi, 1985). The eggs of this insect are laid on the pods or on seeds whose contents are eaten by the larvae. The infestation frequently continues in storage. Bruchid beetles can be controlled by fumigating the pods / seeds with phosphine, ethylene bromide, carbon tetrachloride or acrynitrile, where their use is allowed. Other bruchids, e.g. *Caryedon serratus,* can also use tamarind as a host, this being the important groundnut bruchid (Sundia and Akhil, 2004). It attacks tamarind in India, Colombia, Puerto Rico, Egypt, South Africa, Australia and New Caledonia (Mital and Khamna, 1967; Valez Angel, 1972; Timyan, 1996; Delobel *et al.*, 2003).

The lac insect *Kerria lacca* Ker (Hemiptera: Lacciferidae), whilst not considered a major pest, is a widely distributed polyphagus insect in India which attacks tamarind stems, twigs and leaves, and many other cultivated and wild plants. Removing the affected parts in early stages, as commonly practised by farmers, can control the lac insect. In serious infestations, the legal spraying of diazinon or Carbosulphan at 1% solution is effective. *Chionaspis acuminate-atricolour***,** which is a sap sucker, can be controlled in the same way.

Larvae of *Achaea janata* Linn. (Lepidoptera: Noctuidae) are reported to cause heavy losses when epidemics of the moth infest flowers in tamarind plantations in Tamil Nadu (Ahmed, 1990). In such epidemics over 400-650 larvae can be found on a single tree causing serious growth reduction. It is also considered as a serious pest in the Salem district of India, causing damage to flowers and defoliation. Spraying Permethrin at 0.5% solution (5 ml in 10 litres of water) can control this pest. For more information regarding the legal restrictions of these products the reader is refered to: http://www.pesticideinfo.org/Detail_ChemUse.jsp?Rec_Id=PC35397.

Several coccids are reported as polyphagus pests of tamarind such as: *Aspidiotus destructor* Signoret, *A. tamarindi* Green, *Cardioccous castilleae* Green, *Hemiberlesia lataniae* Signoret, *Howasdia biclavis* Comstock, *Pinnaspis strachani* Cooley, *P. temporaria* Ferris, *Unaspis articolor* Green and *Saissetia oleae* Bernard. Where permitted, the spraying of Carbosulphan at 0.1% solution or Dimethioate at 3% solution (20-40 ml in 10 litres of water) can control all of these coccid species.

Aphids are serious pests that attack tamarind and many other plants. *Toxoptera aurantii* Fonscolombe (Hemiptera: Aphididae) is a major pest which sucks the sap of tender shoots and leaflets causing them to become distorted and covered with moulds growing on the secreted honeydew. White fly, *Acaudaleyrodes rachipor*a Singh (Hemiptera: Aleurodidae) is a minor pest of tamarind. Aphids and white flies can be controlled by spraying Endosulphan at 1 ml in 10 ml of water or Dimethioate at 3% solution (20-40 ml in 10 litres of water), repeated every two weeks until the pests are no longer observed.

Several other minor pests of tamarind have been recorded. *Thalassodes quadraria* Guenee (Lepidoptera: Goemetridae) is a minor pest of tamarind in India and Sri Lanka. Bag worm caterpillars, *Chaliodes vitrea* Hampson and *Pteroma plagiophleps* Hampson (Lepidoptera: Psychidae) have also been recorded as minor pests of tamarind foliage (Nair *et al.*, 1981). However, these can be major pests of other trees such as *Albizia falcataria*. *Stauropus alternus* Walk. (Lepidoptera: Notodontidae), the lobster crab caterpillar, is a minor pest which also attacks tea and pigeon pea (*Cajanus cajan)* (Butani, 1979). *Cryptocrameri* spp. Westwood (Lepidoptera: Psychidae) and *Euproctis scintillans* (Lepidoptera: Lymantriidae), both polyphagus species, have been recorded as defoliators of tamarind (Brownie, 1968). Adults of some species of *Myllocerus* (Coleoptera: Cuculionidae) such as *M. blandus, M. dicolor* (Beeson, 1941) and *M. viridinus* (Kareem, 1965) are reported as foliage feeders causing minor damage to tamarind. Other foliage feeders are the butterfly larvae *Charaxes fabius* Fabr. and *Taragama siva* Lef., which feed on the leaves. Beetle larvae of *Lochmaeocles* spp. (Cerambycidae) are reported to cause damage to branches in Brazil (Cavalcante *et al*., 1977). These Lepidoptera pests can be controlled by spraying Permethrin at 0.5% solution (5 ml in 10 ml of water).

The ripening pods of tamarind are attacked by caterpillars of *Aphomia gularis* Zeller (Lepidoptera: Piralidae) in South India. Stored fruits are commonly infested with *Paralipsa gularis* Zellar and *Corcyra cephalonia* Stnt. in India (Butani, 1978). The larvae attain a maximum size of 18 mm and are stout, greyish in colour with brownish spots. The caterpillars of *Assara albicostalis* Walk. (Lepidoptera: Pyralidae) bore inside the fruit and eat the pulp and sometimes bore into the seed.

Calandra linearis beetle also attacks fruits and is reported as a common pest in Florida and Hawaii (NAS, 1979). Neem *(Azadirachta indica* L.) oil at the rate of 5 to 20 ml per kg of seed, has been used effectively to control bruchid beetles attacking tamarind pods and seeds. The use of neem oil has pronounced adulticidal and ovicidal effects, which are maintained over six months, without any effect on seed viability. This low cost bio-pesticide is very cost effective and efficient in protecting seeds of tamarind from bruchid damage. The method is widely used in the Sahel (Cardet *et al*., 1998). As neem trees are grown in the arid and semi-arid tropics where tamarind also grows, use of neem oil, which can be easily extracted by simple methods, should complement or replace the use of chemicals to control bruchids. Clove oil has also been shown to be a protectant for stored seeds preventing attack by brachids (Lale and Marina, 2002): this was recorded in Nigeria where peanut and tamarind are common. This pest can also be controlled by fumigation with phosphine from aluminium phosphide tablets weighing 3 g each, applied at 0.5 tablet/ton. Ethylene bromide, carbon tetrachloride and acrylnitrile could also be used for fumigation of stored tamarind products (Mital and Khanna, 1978). For more information regarding the use of these products the reader is refered to:
http://www.pesticideinfo.org/Detail_ChemUse.jsp?Rec_Id=PC33216.

Larvae of *Alphitobius laevigatus* Fabr., *Echocerus maxillosus* Fabr. and *Uloma* spp. are other minor pests that attack tamarind fruits. The beetles of *Lasioderma serricorne* Fabr. (Coleoptera: Anobiidae), *Lasioderma* spp*., Calandra linearis* Herbst. (Curculionidae) and *Tribolium cataneum* (Tenebrionidae) are reported to bore into the fruit and cause considerable damage (Singh and Ahmed, 1989). *Dichocrosis punctiferalis* Guenee (Lepidoptera: Pyralidae) and *Phycita orthoclina* Meyrick are reported as fruit boring insects of minor importance (Butani, 1979). *Cryptophalebia illepida* Butler (Lepidoptera: Tortricidae), a polyphagus species has been found boring into the fruits of tamarind (Usman and Puttarudriah, 1955). In some seasons, fruit borers cause serious damage to the mature fruits causing losses to marketable yield (Salim *et al.*, 1998). If fruits are left for long periods on the trees they become infested with beetles, which can also carry over into storage. Termites (*Cryptotermes hainanensis* (Isoptera: Kalotermitidae) attack trees in Hainan, China (Ping, 1987).

Nematodes are also reported to attack tamarind. The major nematodes are: *Radapholus similis,* the burowing nematode, and *Meloidogyne incognita*, the common rootknot nematode. In South India in particular the burrowing nematode is reported to be a serious pest of both tamarind and the coconut palm (Sosamma and Koshy, 1977).

Much more research is needed on the biological control of many of the pests, using natural parasites or predators, in order to reduce the use of chemicals and move towards an environmentally friendly form of husbandry.

Monkeys are reported to devour the fruits greedily while animal browsing causes damage to seedlings unless effectively protected in the early stages (Hocking, 1993).

5.5 Major and minor production areas

Precise data on production and acreage of tamarind are quite difficult to obtain, often because most of the fruit is collected from the wild by rural people or harvested from small isolated areas. It is only grown on a major plantation scale in a few countries, e.g. India and Thailand. Thus, information on area and quantity of production are either non-existent or unreliable and most are estimates. In this section attempts are made to gather as much information as possible on the existing production areas as well as on other areas potentially suitable for tamarind growing.

5.5.1 Present production areas

At present tamarind is cultivated in 54 countries of the world: 18 in its native range and 36 other countries where it has been introduced The major areas of production are in the Asian and American continents.

In most countries, tamarind is a subsistence tree crop used to meet local requirements, although some of the crop is also exported. Consequently, although it is grown in many countries, production and export data are not available. 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 although hard, has little commercial value, but is used at the local level. Product diversification is taking place slowly in a few countries such as Thailand, Indonesia, Philippines and some African countries. Although the potential is high, this species remains underutilised.

India is the world's largest producer of tamarind products. The tree mostly grows wild, although it is cultivated to a limited extent. It is particularly abundant in the Indian States of Madhya Pradesh, Bihar, Andhra Pradesh, Karnataka, Tamil Nadu and West Bengal. In Bajapur, on the Deccan Plateau, the tree is famous for its fine cultivars and is cultivated extensively. Production in India is mainly concentrated in the drier southern states, and the produce is collected by villagers and sold in the open market. Tamarind is not grown on a plantation scale but trees in patches are common in the villages in many states. In some parts of India, it naturally regenerates on wastelands and forestlands. India has traditionally exported processed tamarind pulp to Western countries, mainly the European and Arab countries and more recently to the United States of America. The annual export to the US exceeds 10,000 tons earning about Indian Rs 100 million (US$ 2,165,000).

More recently, Thailand has become a major producer of tamarind, with sweet and sour cultivars in production. The total planted area of tamarind in Thailand is 105,785 ha (661,158 rai) with the area in production being 60,451 ha (377,816 rai) and the non production area being 45,335 ha (283,342 rai) (Department of Agricultural Extension, 1998). Thailand is particularly prominent due to the availability of the sweet tamarind types grown there. In the south and northeast of the country small sweet tamarind orchards have been established by smallholders to produce fresh fruits. Research programmes have been started to improve the cultivars, cultural practices, processing and storage, as the potential for both local consumption and export has been recognised. Thailand has an expanding horticultural industry and tamarind is considered important; similar in importance to guava and citrus. Product development has also taken place and toffees and many other sweet preparations are sold in the market.

Mexico also produces tamarind commercially, with over 4400 hectares producing over 37,000 tons of pulp. It exports a small amount of processed pulp to Central and South American countries and to the United States of America. Information on production and yield in different states is not available although the potential for expansion is reported to be high but remains unexploited (Hernandez-Unzon and Lakshiminarayana, 1982).

Costa Rica is also showing high potential for expansion of tamarind production. In recent years its production has increased consistently. In 1995, 1996 and 1997, production was 192, 205 and 221 tons respectively (Anon, 1999).

Africa, on the whole does not produce tamarind on a large commercial scale, though it is used widely by the local people.

Many other countries have minor production areas of tamarind and depend on naturalised wild stands. In most of these countries, production data are not available because the tree is unimportant for both domestic use and commerce. A major problem is that the species has not been considered for improvement either by the forestry or the horticultural sectors. Information on culture and utilisation is also unavailable, except the traditional knowledge that exists in regard to its use in cooking and as herbal medicine. In addition to the countries mentioned above, there are some other countries for which little or no information exists on their tamarind production and acreage. The major and minor producing countries are shown in Table 5.1.

Table 5.1 Major and minor tamarind producing countries
(- indicates figures unavailable, no production data available for minor areas)

Major areas	Production (tons) and year	Minor areas
Brazil	-	Bahamas
Costa Rica	221 (1997)	Bangladesh
Cuba	-	Burma
Egypt	-	Cambodia
Guatemala	-	Dominican Republic
India	250,000 (1964)	Fiji
Indonesia	-	Gambia
Mexico	37 (annually)	Kenya
Nicaragua	-	Pakistan
Puerto Rico	23 (1977)	Senegal
Philippines	-	Tanzania
Sri Lanka	-	Vietnam
Thailand	140,000 (1995)	Zambia
Venezuela	-	Zanzibar

The wide variety of uses for tamarind in many of the countries has not been exploited, although in the future the area and extent of production are likely to increase as tamarind assumes greater recognition and importance.

5.5.2 Potential production areas

There exists a considerable land area where tamarind growing could be expanded in its native range, but due to low priority allocation, many countries have not identified areas that could be used for expansion (Nyadoi, 2004). Potential production areas for tamarind depend on the demand for tamarind products. Areas may range from scattered trees for personal use by producers to plantations for market production. The initial spread of plantations is likely to occur around the current production centres where technology, skill and marketing channels are already in place. Application of standards for products could increase competition. Cultivation is likely to spread to arid and semi-arid areas, resource-poor areas and wastelands where other crops cannot grow, because such land usage is receiving increased attention.

5.5.3 Large and small scale production

Large plantations may be established on community lands as agroforestry or as co-operative plantations using improved cultivars. Although better land quality and water supply would ensure better quality fruits, large areas of wasteland may also be developed. The establishment and management of such plantations may require specialised soil treatment, protection against wild animals, attention to transportation and distribution of fruits, and selection of specific cultivars.

Large plantations can be established for specialised markets, including processing and export. As the number of tamarind cultivars increase, different plantations will grow trees for different markets, as is the case in Thailand with sweet and sour fruit types. The quality of the fruit needed for processing will be different from the quality required for the sale of fresh fruit. Such plantations would most likely be situated close to the cities, where the facilities for packing and transport are close at hand. The chances of success of plantation growth are high using science-based inputs such as new cultivars and root stocks, production of quality planting material, fertilisation and integrated pest management.

Small plantations such as those on farm boundaries, roads and field edges can meet the local requirements for villages and small towns. Fresh fruit are already sold in the village markets.

Growing tamarind in home gardens in association with food and other crops can be both profitable and aesthetic. Tamarind trees also make attractive ornamentals in landscape plantings. Production of tamarind for home consumption assists in providing nutrition security, especially in drought-prone regions where fresh fruit is a small component of the daily diet. Fresh fruits are already sold in the village markets in many countries. In such areas the number of trees planted need only meet the local requirement for fresh and processed fruits. Tamarind trees also enhance the genetic richness of farm and garden plots, thus contributing to their ecological stability. Indeed in fragile environments neglected species like tamarind may well be more valuable and more appropriate than conventional crops. Smallholders need to have access to quality planting materials and appropriate production technologies. Furthermore, development of post-production handling, processing and transportation is necessary to raise quality, minimise losses and facilitate movement from farmers to markets.

5.5.4 Commercial prospects

There exist good business prospects for tamarind in many tropical and subtropical countries. The potential to develop a comercial tamarind industry is excellent provided that such development is targeted to an industry based on reliable production, post-harvest processing and marketing. Export oriented plantations of tamarind will also require technology inputs by producers to the production, post-harvest processing and marketing systems. The development of interest in organic production by consumers will also enhance opportunities for export.

Plate 1. An inflorescence showing floral parts and sequential development of flowers and fruits (Photo: D.K.N.G. Pushpakumara)

Plate 2. Tamarind pods
(Photo: A. Latham)

Plate 3. Removing bud from scion for bud grafting

Plate 4. Removing bark from rootstock

Plate 5. Fitting bud to rootstock (Photos: A. Latham)

Plate 6. Cleft grafting

Plate 7. Graft union wrapped in polythene tape
(Photos: K.El-Siddig)

Plate 8. Bark removed from stem for air-layering

Plate 9. Stem and rooting media covered in black polythene
(Photos: K.El-Siddig)

Plate 10. Mass flowering of tamarind in Sri Lanka during 2005 September (Photo: D.K.N.G. Pushpakumara)

Plate 11. Variation in tamarind pod size (Photo: Gunasena and Hughes, 2000)

Plate 12. Variation in tamarind seed size (Photo: Gunasena and Hughes, 2000)

Plate 13. Variation in flower colour - red flowers (Photo: Gunasena and Hughes, 2000)

Plate 14. Variation in flower colour - white flowers (Photo: Gunasena and Hughes, 2000)

Plate 15. Variation in dark red and brown pulp colour in tamarind (Photo: Gunasena and Hughes, 2000)

Plate 16. Dehusked pods
(Photo: A. Latham)

Plate 17. Processed products
(Photo: ICUC)

Chapter 6. Reproductive Biology

D.K.N.G. Pushpakumara and H.P.M. Gunasena

6.1 Introduction

Natural or unselected tamarind is a long-lived tree and once it starts bearing, its fruiting capacity increases with age. The productive life of a tree can last for 50-70 years after which it declines. The normal lifespan of the tree is approximately 150 years.

It is important to understand the variation in time of the juvenile phase and genotypic and phenotypic variations in flowering, fruit setting and productivity so that domestication can be enhanced. See Plates 10-15 for variation in flowers and fruits.

This chapter summarises what is known about the reproductive biology of the tree.

6.2 Flowering and fruiting phenology

In tamarind, terminal vegetative shoots which bear flowers only in the following flowering season are produced annually. Two types of terminal shoots have been observed by Nagarajan *et al*. (1997), short ones with an erect habit and long ones with a drooping habit. This has been identified as a useful character to evaluate genotypes, since terminal shoot length and foliage production are found to be highly correlated. In an inflorescence the flowers only open on alternative days. Flowering and fruiting times vary from country to country and region to region depending on the latitude and altitude. It is reported that production of flowers varies considerably between selections in India. Those with longer vegetative terminal shoots produce more flowers. The range of variation of flowering and floral organs is illustrated in Table 6.1.

In general, flowering and fruiting of tamarind takes place in the dry season. An extended spell of dry weather may be essential for fruit development, and trees which grow in the humid tropics without this dry spell often do not bear fruit. At higher altitudes shoots grow mainly in spring and flower throughout the summer. In the monsoon climate of East Java the tree changes its leaves towards the dry season (September to November), and some trees may be nearly leafless during this dry period. Shoot growth continues through the rainy season (November to April) during which period flowering occurs. In Thailand, tamarind sheds its leaves and produces new ones towards the end of the dry season (March to April). Sometimes trees are leafless for a brief period, though they often remain foliated. Spasmodic or incidental shoot growth continues into the dry season but in May the trees are usually quiescent. Trees are often foliated, but may be briefly leafless for short periods in hot, dry localities (Chaturvedi, 1985). Shoot growth continues through the rainy season into the dry season. The new leaves appear in March to April.

Flowers emerge on new shoots produced in the spring or summer in most countries. However some trees flower as late as July or August in the rainy season. This common phenomenon is a problem in orchard management, particularly orchards of sweet tamarind. In India early, mid and late flowering types of tamarind have been identified and those with delayed flowering habit are reported to be high yielders (Usha and Singh, 1994). In East Java, the flowers appear from April to June. In Zambia, flowering occurs in the hot dry season (October onwards). North of the equator, flowering is from April to May. In Ethiopia, flowering is from March to July (FAO, 1988). In Sri Lanka, the fruiting season is from February to June (Macmillan, 1943; Worthington, 1959). Mass flowering is common in tamarind during the flowering season (Plate 10). However, in some trees flowers can be seen at any time during the year and may be due to genotype x environment interactions (Jayaweera, 1981; Coronel, 1992; Nagarajan *et al*., 1997).

The period from flowering to pod ripening is 8-10 months. Ripe fruits, however, may remain on the tree until the next flowering period. In most of the tamarind producing countries the fruits are harvested from February to March/April, but sometimes the harvesting period may extend to June (Coronel, 1992). In India, fruits are harvested from April to May although in Kerala and other parts of South India fruit collection may be over by the end of February. In Florida, Central America and the West Indies the ripe fruits are available from April to June (Bueso, 1980). In Hawaii, ripening takes place in summer and late fall. In Nicaragua, the harvesting period is early, usually from December to March. In the Philippines, the ripening period is from May to December with a peak in August-October. In Sri Lanka, fruits ripen from January to February to June (Macmillan, 1943; Worthington, 1959). Pods ripen in the spring at high altitudes. In Thailand the fruiting season is December to February. In the Philippines, the fruiting season is from May to December with a peak in August to October (Coronel, 1992).

North of the equator, fruit ripening is late in autumn or winter (December to January). In Zambia, fruiting is in the following cool dry season after the main dry season (July to November). In Ethiopia, fruiting is during the dry season, September to April (FAO, 1988). Mahadevan (1991) has observed a noticeable tree-to-tree variation in flowering and fruit ripening in India. Similar observations were also observed in Sri Lanka.

Table 6.1 Variation of flowering and floral organs seen in different cloned selections in India

Characteristic	NBN1	NBN2	Clone NBN3	RDB Patna	JRK	Standard Error of Means	LSD	CV (%)
Inflorescence length (cm)	4.38	4.85	5.70	5.07	4.91	0.11	0.23	3.50
Inflorescence per branch	7.56	13.69	13.59	16.32	11.92	0.17	0.37	2.18
Flowers per inflorescence	13.28	8.05	15.57	17.09	12.21	0.02	0.05	0.30
Flowers per branch	100.47	109.12	212.70	279.80	145.61	2.77	5.87	2.58
Style length (mm)	4.57	4.62	4.74	4.30	4.64	0.06	0.14	2.24
Ovary length (mm)	6.60	6.74	6.61	6.13	6.21	0.04	0.08	0.93

Source: Nagarajan *et al*., 1997

Note: NBN, RDB Patna and JRK are tamarind clones identified from Gottipura, Karnataka State, India.

6.3 Anthesis and stigmatic receptivity

Observations carried out in Sri Lanka revealed that anthesis starts at 16.30-21.00 hrs and flowers completely open by 04.00hrs. Anther dehiscence occurs from 7.00-11.00 hrs. In India, anthesis starts at about 16.00-20.00 hrs and flowers are completely open by 02.00 hrs. Anther dehiscence occurs from 08.00-10.00 hrs in the morning (Thimmaraju *et al*., 1977; Nagarajan *et al*., 1997). Tamarind stigmas are receptive for nearly 48hrs with peak receptivity on the day of anthesis (Thimmaraju *et al*., 1977; Nagarajan *et al.*, 1997). Based on the timing of stigma receptivity and anther dehiscence, tamarind is classified as a protogynous species.

6.4 Pollen morphology and pollination vectors

Pollen grains are dimorphic, radially symmetrical, tricolporate, oblate-spheroidal in shape and sticky (Perveen and Qaiser, 1998). Nagarajan *et al.* (1997) showed pollen dimorphism in tamarind with two distinct sizes of pollen grains : 40-42 µm and 22-25 µm. This size variation was attributed to resource limitation towards the latter part of the flowering season. Smaller pollen grain counts increased during the later part of the flowering. Pollen sterility is very low in tamarind (less than 2%). Under ambient conditions (37-40^0 C) pollen viability was observed to be 88% for three days, while pollen stored at 4^0 C remained 97% viable up to 100 days. Variation of pollen sterility, dimorphism and viability of different tamarind clones are given in Table 6.2.

Studies carried out in Sri Lanka revealed that tamarind pollen grains are sticky and the flowers produce nectar. Sticky pollens are not efficient for wind pollination. Honey bees (*Apis* spp.) are common visitors to tamarind flowers particularly between 08.00-11.00 hrs and 16.00-18.00 hrs. Observations of honey bee activity on flowers and their visitation patterns suggest that they are effective pollinators. Thus, pollination is mostly by honey bees. Prasad (1963) also suggested that tamarind is insect pollinated due to its floral characters and the presence of copious levels of nectar. Similar observations were also made in India by Nagarajan *et al*. (1997) and Thimmaraju *et al.* (1977). Arroyo (1978) also suggested that honey bees are the most common pollination vector among leguminous species including tamarind. Insect visitation in tamarind peaks between 08.00 hrs and 11.00 hrs which is compatible with stigmatic receptivity and anther dehiscence.

Studies in Coimbatore in India observed the foraging of flower visitors. Tamarind flowers mid-May to mid-July but natural fruit set is low: 3-5% compared to 70-90% in controlled experiments. A range of insects belonging to Hymenoptera, Lepidoptera, Hemiptera, Diptera and Thysanoptera visited. Bees are the major pollinators. Domesticated honeybees ensure pollen transfer and fruit set (Sasidharon *et al*., 2003).

An experiment was conducted to evaluate the effectiveness of foliar sprays of cycocel (1500 ppm), Ethrel (500 ppm), Triacontanol (20 ml $tree^{-1}$), IBA (150 ppm), Planofix (100 ppm), micronutrient mixture (0.5%), $ZnSO_4$ (0.5%) + boric acid (0.3%) + $FeSO_4$ (0.5%) and urea (1.5%) on flowering pod set and fruit retention at Tamil Nadu Agricultural University, Coimbatore. All the treatments with growth regulators and chemicals exhibited significant effects on flowering, pod set and retention. Treatment with foliar feeding urea resulted in maximum numbers of flowering (75.7%) and cycocel resulted in maximum pod set (32.3%) and retention (54.7%) per unit area (Ilango and Vidyalakshri, 2002).

Table 6.2 Clonal variation of sterility, dimorphism and viability of tamarind pollen

Characteristic	Clones					SEM	LSD	CV (%)
	NBN1	NBN2	NBN3	RDB Patna	JRK			
Pollen sterility (%)	1.18 (1.08)	1.13 (1.06)	0.79 (0.88)	1.80 (1.33)	1.93 (1.38)	0.04	0.08	5.26
Pollen dimorphism (%)	11.03 (3.32)	13.39 (3.65)	12.08 (3.47)	9.63 (3.10)	10.23 (3.19)	0.04	0.08	1.86
Pollen viability in ambient storage (%)	88.00 (9.38)	88.20 (9.39)	84.80 (9.20)	85.60 (9.25)	86.60 (9.30)	0.15	NS	2.46
Pollen viability in cold storage (%)	97.40 (9.87)	96.80 (9.84)	97.00 (9.85)	96.60 (9.83)	97.00 (9.85)	0.03	NS	0.52

Source: Nagarajan *et al*., 1997.
Note: NBN, RDB Patna and JRK are tamarind clones identified from Gottipura, Karnataka State, India. NS=Not significant. SEM=Standard error of means. The values in parenthesis are transformed means (square root transformation).

6.5 Fruit set, breeding and mating system

In spite of profuse flowering, fruit set in tamarind is very low under open pollination. Studies carried out in Sri Lanka revealed that about 10-15% of flowers developed as fruits although Nagarajan *et al.* (1997) observed only 1-2% of flowers developed as fruits. This may be due to the short-lived nature of the flowers (about 48 hours) and also due to pollinator limitation, thus many flowers appear not to be pollinated during their short stigmatic receptive period. All unpollinated flowers drop within two days. In contrast in controlled cross pollination fruit set was more than 75% whilst controlled self-pollination resulted in 2-6% fruit set (Table 6.3) (Nagarajan *et al.*, 1997). Usha and Singh (1996) also reported that controlled 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 whereas it increased to 56% with cross-pollination.

Table 6.3 Fruit setting in tamarind cultivars under open and controlled pollinations

Treatment	Clone					SEM	LSD	CV
	NBN1	NBN2	NBN3	RDB Patna	JRK			(%)
Open pollination (%)	1.65 (1.28)	2.32 (1.51)	1.15 (1.07)	1.47 (1.21)	1.44 (1.19)	0.08	0.17	10.3
Self pollination (%)	2.40 (1.51)	6.80 (2.59)	2.60 (1.59)	4.60 (2.13)	NA	0.12	0.23	8.6
Cross pollination (%)	84.20 (9.16)	88.20 (9.39)	87.40 (9.34)	75.80 (8.70)	NA	0.18	0.39	3.1

Source: Nagarajan *et al.*, 1997.
Note: NBN, RDB Patna and JRK are tamarind clones identified from Gottipura, Karnataka State, India. NA=Not available. SEM=Standard error of means. The values in paranthesis are transformed means (square root transformation).

Based on the results of controlled pollination experiments, Nagarajan *et al.* (1997) suggested that tamarind is a self-incompatible species. No fruit set was observed following exclusion of pollen during controlled pollination experiments suggesting that tamarind is not an apomictic species. Similar observations were also made in an on-going study in Sri Lanka. Although different clones respond slightly differently in controlled pollination treatments, the trend of results seems common for all types of tamarind (Nagarajan *et al.*, 1997).

Tamarind is a predominately outcrossing species with some level of selfing. This may be the reason for bearing of fruits even in isolated trees. Shanthi (2003) studied isozyme analysis of the mating system (with Aat, Adh and Pdh loci) of tamarind using open pollinated seeds from 225 individuals from Dharmapuri populations in India. Results revealed that single and multi-locus outcrossing rates of tamarind were 0.68 and 0.67 respectively. High levels of within population variation and low levels of between population variations observed by Shanthi (2003) also revealed that the species is highly outcrossing. Heterogamous floral adaptation, protogyny and self-incompatibility observed in tamarind may promote outcrossing under natural conditions.

Fruit set in tamarind is influenced by environmental factors, age and size of shoots, carbon : nitrogen ratio and the hormonal balance under which the trees are grown, hence, high seasonal and annual yield variations can be expected. Feungchan *et al.* (1996 c) attempted to increase fruit set of sweet tamarind by the application of growth regulators at the time of flowering (see also Chapter 6.2 where growth regulators and nutrient spray was noted to affect flowering and subsequent fruit set). 4-CPA at 15 ppm , NAA at 100 ppm or GA 3 at 15 ppm were effective in increasing tamarind fruit set. The growth regulator 4-CPA at 15 ppm was the most effective (Table 6.4). The inducement of fruit set and fruit numbers per tree in sweet tamarind by spraying growth regulators will be an important cultural practice, as is the case of pineapple for year round fruit production. Further studies will be required to establish the type of growth regulator, and its rate and time of application for regular and enhanced pod yields.

6.6 Fruit development

Fruit development in tamarind has three distinct stages: growth, maturation and ripening. The indehiscent pods ripen about 8-10 months after flowering and may remain on the tree until the next flowering period (Benthall, 1933; Chaturvedi, 1985; Rama Rao, 1975). In Mexico the fruits begin to dehydrate 203 days after fruit set and continue until 245 days when full ripeness occurs and up to half the fruit's original water content is lost. The fully ripened fruits can remain on the tree for six months. Fruits are harvested at two stages depending upon the market. Green pods are harvested for flavouring and ripe pods for processing. The fruits of sweet types are also harvested at two stages, half ripe and fully ripe. At the half ripe stage the pulp is yellowish green and has the consistency of an apple, particularly in the case of sweet forms. At the fully ripe stage the pulp shrinks, due to loss of moisture, and changes to reddish brown and becomes sticky.

Table 6.4 Effect of growth regulators on fruit setting of sweet tamarind

Growth regulator	Rate (ppm)	Pods/plant
4CPA	10	144
	15	216
NAA	100	117
	150	107
GA3	10	72
	15	103
SADH	200	83
	300	80
Control	-	81

Source: Feungchan *et al*. (1996 c).

Chapter 7. Genetic Improvement

H.P.M. Gunasena and D.K.N.G. Pushpakumara

7.1 Introduction

Although tamarind is an ancient domesticate, little attempt has been directed to its genetic improvement. This is understandable because tree improvement research that combines developmental and operational phases is time consuming and the large scale cultivation of tamarind is still in its early stages. Indigenous farmers have however selected planting materials from natural populations based on desirable and observable characteristics but such phenotypic selection means the growing stocks are virtually wild.

Tamarind was recorded over a century ago as a variable species especially for pulp colour and sweetness (von Mueller, 1881). Since there is such extensive variation in characters such as foliage, flower and pod production and timber quality (Table 7.1), there is a considerable scope to improve the species. Improvement holds the key for boosting productivity and yield of the orchards and involves development of genotypes possessing desirable characters like fast growth, good tree form, high yield and resistance or tolerance to major pests, diseases and drought (Radhamani *et al*., 1998). Since the variation in pod length and pod width was found to be genotypic (Shivanandam and Raju, 1988; Hanamashetti, 1996). Similarly for other trials the potential for improvement depends on sampling the genetic variability available within and between populations. Hence, knowledge of genetic variation and structure of a species and genetic parameters of important traits are essential to develop effective improvement and conservation strategies.

7.2 Understanding the variations

The apparent high observable variability within and between populations (Table 7.1) indicates that speedy benefits may be obtained by selecting superior trees within provenances and propagating such stocks as clones. A considerable variation in growth characters such as shoot length, root length, germination percentage, plant height and pinnae per plant has also been observed in different populations (Challapilli *et al*., 1995; Bennet *et al*., 1997; Divakara, 2002; Shanthi, 2003). Recent studies on isozyme analysis of ten tamarind populations from Coimbatore, India identified 12 loci with 25 alleles (Shanthi, 2003). All populations had more than 50% polymorphic loci (range from 50-75%). The mean number of alleles per locus was 1.85 (range from 1.6-2.0). Mean heterozygosity observed among 10 populations ranged from 0.085-0.154 whilst mean heterozygosity expected according to the Hardy-Weinberg equilibrium ranged from 0.163-0.258.

Table 7.1 Variation of characters observed for tamarind

Character	Variation
Terminal shoot length	Short-long
Flowering behaviour	Early-mid-late
Number of primary branches	5-8
Number of secondary branches	30-63
Number of tertiary branches	45-91
Number of inflorescences/branch	531-990
Number of flowers/branch	5697-15587
Number of fruits/branch	748-1595
Pod length (cm)	4-30
Pod width (cm)	1.9-4.0
Pod weight (g)	4.5-60.0
Amount of pulp in ripened fruit (%)	30-50
Single seed weight (g)	0.8-1.2
Number of seeds/pod	4-10
Seed weight (g)	1.6-10.0
Sweetness of pulp	Sweet-sour
Fibre content	Low-high
Pod yield per plant (kg)	Very variable

Source: Bennet *et al.*, 1997; Challapilli *et al.*, 1995; Divakara, 2002; Shanthi, 2003

The mean total genetic variation (H_T) of the 10 tamarind populations was 0.322. The total genetic variation within population (H_S) was 0.291 whilst variation between populations (D_{ST}) was 0.03. The relative extent of gene differentiation among populations (G_{ST}) was identified as 0.115 (Shanthi, 2003). Even though this showed a low level of genetic diversity it was mainly because the populations sampled were from a small geographic region. A high level of within population variation and low level of between population variations also revealed that the species is highly outcrossing, and there is ample individual variation to use in genetic improvement.

Based on the assessment of candidate 'plus' trees and their progenies, Shanthi (2003) concluded that pod size, tree height, number of flowers, number of inflorescences and number of tertiary branches could be used as measures for evaluating tamarind trees in order to select superior trees for further evaluation.

The experiments carried out in Coimbatore revealed that the highest *phenotypic* variation occurred for pod length and the lowest for seed weight whilst the maximum *genotypic* variation has been observed for pulp weight. The highest phenotypic and genotypic coefficients of variation have been recorded for pulp weight (Chundawat, 1990; Challapilli *et al.*, 1995;

Divakara, 2002; Shanthi, 2003). A maximum heritability of 0.5 and the highest genetic advance percentage were recorded over a mean of 42.5 for pulp weight (Table 7.2). The highest genetic advance was observed for pulp weight. Pod length showed highest positive phenotypic correlation with pulp weight. Hence, selection based on pulp weight and pod length is useful in tamarind improvement programmes. Further, because of the presence of significant positive correlation coefficients between pod length and pod width, they are suggested as selection criteria for the identification of superior trees.

Table 7.2 Heritability and genetic advance of tamarind

Character	Heritability	Genetic advance percentage over mean
Pod length	0.30	16.3
Pod width	0.40	10.0
Pulp weight	0.50	42.5
Number of seeds/pod	0.20	13.6
Single seed weight	0.05	2.2

Source: Shanthi (2003).

7.3 Genetic improvement

Genetic improvement through the use of superior clones has been described by Kulkarni *et al.* (1993). Tamarind has a relatively long generation time and is primarily outcrossing, thus any conventional breeding approaches would require considerable investment in time and money. There are trees with very high yielding potential exceeding 800 kg/tree/year and such trees could be selected for vegetative propagation by air layering or grafting methods to produce fast growing trees for local (home garden) and commercial (orchard) use. Such trees can be grown with comparative ease and minimum management and should prove to be profitable due to their commercial value for small-scale farmers in African and Asian countries.

Provenance trials need to be conducted in many parts of the tropics to select the best germplasm for further improvement. Germplasm needs to be rigorously characterised and evaluated to select desirable traits. If quick growing and high yielding strains are selected for different uses, tamarind would rapidly become a desirable tree for small scale plantations in a short period, particularly since it continues to bear fruit for many years. More trait specific research and combining desirable characters together is needed to develop cultivars. An emphasis should be to select for agroforestry systems and small scale plantations. The desirable ideotypes should be developed to fit into various niches of these systems as well as for more intensive commercial production. This will require more attention to tissue culture since it offers a way of cleaning stocks from diseases. Then planting and distribution systems need to be developed to provide materials to growers and even to exchange internationally.

7.3.1 Selection

The selection of elite trees is an important step. These 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, fibre and seed weights, and number of seeds. In India local farmers usually identify mother trees that consistently produce large numbers of fruits for their seed collection and propagation. Some of the trees that have been selected on this basis are reported to have large pods, 25 cm long and 5 cm wide (Jambulingam and Fernandes, 1986).

The major breakthrough in recent years has been the identification of tamarind types with less acidic pulp, commonly referred to as sweet tamarinds. In Thailand and the Philippines, farmers are growing the sweet types on a limited plantation scale and they are also known locally in India. Selections have been made from natural stands growing in these countries. In Thailand, more than 50 sweet tamarind cultivars are grown, while in the Philippines, eight selected cultivars are popular among the farmers. These sweet types have created a resurgence of interest in many countries of the Southeast Asian region and encouraged researchers to undertake studies on tamarind.

The sweet tamarind has been attributed to a point mutation. Occasionally isolated branches on a tree may bear sweet fruits while others bear normal sour ones. Bud sports have been propagated vegetatively and form the basis for a range of recent cultivars.

7.3.2 Participatory improvement

Improvement of multipurpose trees like tamarind should also be participatory, involving farmers in all phases of the programme. As tamarind is presently a smallholder crop, this approach is even more important at this stage, before steps are taken for commercialisation. The local people with their indigenous knowledge could provide information on why they favour a particular selection, and characterisation based on users' perspectives will be an essential starting point for improvement of tamarind. The preferences will also vary from country to country. As such the use of Participatory Rapid Appraisal (PRA) or Diagnosis and Design (D&D) could provide technical information on reproductive biology, propagation techniques, existing conservation, management practices and handling and processing technologies. The approach may be most important for countries which do not have strong national programmes on genetic improvement of underutilised tree species.

7.3.3 Ideotypes

It is essential therefore to identify different ideotypes for different purposes, localities, environments and cultural practices. These then act as reference guides. There is no universal ideotype suitable for all sites and end users. Chuntanaparb and Ranganathan (1990) have described the characteristics of such ideotypes (Table 7.3); they are extensive and to a degree theoretical but are useful points of reference.

Table 7.3 Characteristics of ideotypes for tamarind fruit production

Character	Proposed ideotype for India	Proposed ideotype for Sri Lanka
Product and services required	Pods for edible pulp, wood for fuelwood, timber and charcoal, leaves for fodder, seed for extraction of starch for textile and paper production	Fruit, branches for fuelwood, bole for timber
General selection criteria	Vigour, fruit quality, early fruit set, resistance to pests and insects	Fruit and wood biomass production, vigour, pest and disease free
Required/other information	Fodder value of leaf	Tolerates poor soil, low water consumption, regenerates naturally. Maintained on common lands, in home gardens and along roadsides
Ideotype description		
Crown	Round large canopy with many branches for greater fruit production	
Stem	Large, with no branches up to a height of 2-3 m.	
Shoots	Longer terminal shoot length	
Fruit	Production should begin in the 4th or 5th year. There should be greater yield of fruit with a good yield every year instead of the current cyclical pattern. The fruiting season could be longer. The fruit itself should be bigger and fleshier	
Discussion	Selection criteria should be increased fruit yield and size of pods	

Source: Modified from Chuntanaparb and Ranganathan, 1990.

Ideotype identification should focus on specific services and products that could be marketed, either locally or internationally. The proposed characteristics for a general tamarind ideotype are shown in Table 7.4.

Table 7.4 Proposed characteristics for tamarind ideotype

Tree parts	Characters for desirable ideotypes
Stem/root	Strong, short, 3-5m, multiple branches for sweet types, normal tall trees for sour types Tap root deep and strong
Shoot	Longer terminal shoot
Bearing habit	Early, 4th or 5th year, flowering period long, regular
Fruit	Heavy and fleshy, sweet/acidic pulp depending on market, high pulp recovery, high in nutrients
Yield	High, 600-800 kg/tree/year
Adaptability	Wide adaptability, resistance to pests and diseases

7.4 Enhancing improvement

In order to enhance genetic improvement there is a clear need to understand the variation within the species and this will only emerge when the genepool has been sampled from across its geographical range and analysed. This will lead to the availability to those involved with genetic enhancement of a wider range of germplasm.

Such germplasm will require focused characterisation and evaluation and selection of higher-yielding lines based on phenology (early, regular, and year round production), yield (high pod numbers), desirable fruit characters (weight, real value of pulp, high nutritive composition) and tolerance or resistance to the major pests and diseases.

The use of molecular markers in selection of traits with low heritability will also deserve attention.

Chapter 8. Genetic Resources

H.P.M. Gunasena and D.K.N.G. Pushpakumara

8.1 Introduction

Although there is a wealth of tamarind germplasm across the regions where it occurs in the wild or has been naturalised, no systematic germplasm collection and evaluation has been attempted to date in spite of the current value and future potential of the crop. Most countries have not considered it as a priority species. This may be due to its present modest utility value and wide use in subsistence economies.

Tamarind populations are also not considered endangered and hence there is low priority for its conservation. However, several countries in Africa have prioritised tamarind for conservation. In Sudan prioritisation for genetic conservation has been studied by collecting information through on-market surveys of non-wood products in relation to export and home consumption (FNC/FAO, 1995). These surveys revealed that tamarind products used for home consumption ranked number one among the species studied. Other countries in Africa, (Burkina Faso, Cameroon, Chad, Côte d'Ivoire, Gambia, Guinea-Bissau, Kenya, Mauritania, Nigeria and Senegal) have prioritised it for conservation based on its utilisation and value. Accordingly, the need to explore, collect, evaluate, conserve and use tamarind germplasm has been emphasised (FAO, 1999). These studies as well as other consumer surveys conducted in India (Marothia and Gauraha, 1992) show that although tamarind does not contribute in a major way to the economy nor is it traded extensively in the international market, it is of overwhelming importance to local people in rural areas and worthy of conservation.

8.2 The need for working collections

The wide variability that exists in tamarind in terms of acidity of the pulp, pod bearing ability and pod size has to be used for genetic improvement in countries of Africa, and South and Southeast Asia. In order to incorporate such traits, germplasm collections have to be available in each region for scientists to work on. The collections should be subjected to continued evaluation to select and release desirable types. In this respect an African Tamarind Network has been formed to study genetic variation in the African tamarind under the sponsorship of ICRAF, Nairobi, Kenya, (Simons, 1998 personal communication).

From such diverse germplasm, plants with sweeter, more juicy pulp and other desirable characteristics can be selected for tree improvement programmes. In recent years less acidic, sweet tamarind types have been selected in the Philippines and Thailand and are becoming popular. Tamarind will continue to play a role in tree improvement programmes and sustainable development and it is important that horticultural scientists work with those involved in rural development so that the working collections can span all interests.

Some of the potential characters that could be used in germplasm characterisation are listed in Table 8.1 (see plates 12-15). Studies in Karnataka which evaluated the correlation between different attributes of growth and fruits in 17 genotypes, and others in Thailand, are now standard guides for evaluation (Challapilli *et al.*, 1955; Birdar and Hanamashetti, 2001). The length of the fruit is also reported to be positively correlated with fruit weight, pulp, and number of seeds. Fruit thickness was negatively correlated with fibre weight, seed weight and seed number. Since fruit length, weight and thickness are measures of fruit size, the larger the fruit, the heavier the pulp weight (Shivanandam and Raju, 1988).

8.3 Germplasm activities in different countries

8.3.1 Thailand

In Thailand, wide genetic diversity in tamarind germplasm of both sweet and sour types has been observed in all regions. Germplasm collecting was undertaken in 1986 and 1987. A total of 1811 accessions were collected during this period. Several other accessions, such as No: 86-2-23-017, No: 86-13-008 I and No: 87-2-01-035 have been selected for improvement for industrial purposes (Feungchan *et al.,* 1996 a). Some of the names given to the selections relate to the district from where the clone was first selected (e.g. Jae Hom) or the name of the grower (e.g. Muen Chong).

Fruits with red and brown coloured pulp have also been found in the accessions from Thailand (see Plate 15). At the University of Khon Kaen, cultivar selection is more advanced than in other countries. Several accessions have been selected which are potentially high yielding. In Thailand, there are more than 50 sweet tamarind cultivars under cultivation. They include Muen Chong, Sri Tong, Nam Pleung, Jae Hom, Kun Sun, Kru Sen, Nazi Zad and Sri Chompoo. A cultivar commonly grown and popular with Thai farmers is Makham Waan.

Table 8.1 Characters useful to distinguish tamarind cultivars

Plant part	Character
Tree	Tree form
Shoot	Terminal shoot length
Flower	Colour of petals (dark pink to whitish cream) Number of inflorescences per branch Number of flowers per inflorescence Flowering pattern (early - late)
Pod	Pod form, length, breadth, curvature, shape Pod weight Colour of shell
Pulp	Pulp colour, (red/whitish) Pulp:shell ratio Real pulp value Pulp yield Pulp recovery percentage Fibre content Ease of pulp extraction Colour Weight of pulp
Seed	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) Ranges of protein, mineral and amino acid composition
Others	Resistance to salinity, drought, degraded soils, waterlogging, high pH, low pH, grazing, diseases and pests

Thai researchers developed a specific formula for primary screening. The formula is expressed as Real Value of Pulp (RVP) where:

RVP = (Percentage pulp weight) x (Pulp weight / 100).

Based on the RVP seven outstanding accessions were identified out of 283 accessions (Table 8.2).

Table 8.2 Accessions selected in Thailand based on RVP

Accession No.	Real value of pulp (%) (RVP)	Rank
87-2-01-035	20.20	1
87-2-0l -029	18.39	2
87-1-02-001	17.98	3
87-1-02-002	15.00	4
87-1-02-003	12.00	5
87-1-02-004	11.28	6
87-1-02-005	10.80	7

Source: Feungchan *et al.,* 1996 a.

In this study, it was also found that excellent accessions had RVP values of over 21 and the number of pods was about 13-15 per kilogram. Most of the best accessions were found in provenances along the Mae Kong River, but the role of the river in all these cases has not been fully understood. Based on RVP values, 51 outstanding accessions are undergoing further evaluation.

Thailand is also paying attention to the percentage of tartaric acid and sugar, the main determinants for taste and flavour. Accessions have been selected for improvement for industrial purposes. One accession (No: 86-2-23-017) has given the highest content of tartaric acid (up to 11.2%) and has potential for commercial extraction of tartaric acid. Another accession (No: 86-13-008) had a sugar content of 39.9% and could be valuable for fructose production. Yet another accession (No: 87-2-01-035) was found to give the highest concentrated tamarind flesh and this is suitable for processing into sauces, drinks and confectionery.

8.3.2 Philippines

Variation has been observed in fruit forms in the Philippines. Some are oblong and short, while others are long and curved. Sweet and sour types are found in different parts of the country. Several trees bearing sweet fruits have been found in Cavite and Laguna. The University of the Philippines at Los Banos long ago selected and identified sweet tamarind varieties, namely Cavite, Batangas, Bulacan, and Laguna. These varieties have long plump fruits with thick sweet pulp. Some of the sweet types have pods 7-10 cm long and 2-3 cm wide, weighing 20-30g, containing thick sweet pulp with 6-7 seeds. Forty-six accessions of tamarind germplasm are presently available in the Institute of Plant Breeding, Los Banos, Philippines.

The varietal characteristics of tamarind lines introduced from the Philippines have been evaluated at the US Department of Agriculture, Subtropical Horticulture Research Station at Miami, Florida (Knight, 1980) and the station developed a cultivar called ‘Manila Sweet’.

8.3.3 India

In India, most of the area under tamarind cultivation is planted with unselected, inferior cultivars. Selections from tamarind provenances are available. The Bharata Agricultural and Industrial Foundation (BAIF), Pune, India has attempted to supply improved planting material to smallholders by selecting superior trees from among existing natural populations. The parameters for selection of superior trees have been based entirely on pod characters such as pod length, pod colour and pulp yield per pod (Daniel, 1999; personal communication) and the association of fruit characters has been worked out (Karale *et al*., 1999), as well as genotype x environment effects of different locations on fruit size grades (Parameswari *et al*., 2000). Under this programme, 15 superior tamarind provenances have been identified and a multiplication stand has been established in the BAIF's Central Research Station in Pune. Among them, selections such as Prathisthan from Maharashtra and Periyakulam (PKM-1) and Urigam from Tamil Nadu are well established and preferred by farmers. The most preferred cultivar is Periyakulam 1 (PKM-1), a sour type, a clonal selection from a local form in a village named Endapalli near Periyakulam. The Horticultural Research Station of the Tamil Nadu Agricultural University, Periyakulam, released this cultivar which is an early bearer, especially when grafted when they come into bearing from the third year (compared with the fifth year in the local form). It has a pulp recovery percentage of 39% compared to the local cultivar which is 28%. The yield is also higher in the Periyakulam cultivar, with 263 kg/tree against 167 kg/tree in the local cultivar (Daniel, 1999, personal communication).

Studies were also undertaken to select high yielding cultivars based on their flowering pattern. In seedling populations, early, mid and late flowering tamarind types have been identified. Duration of flowering is longer in late flowering trees than in mid and early flowering trees. In mid and late flowering trees natural cross-pollination is greater than with early flowering trees which are mostly self-pollinated under natural conditions. Hence mid and late flowering trees can be selected and are most suitable for selection for improvement (Usha and Singh, 1994).

There is also interest in India in using fruit tree genotypes for ameliorating marginal farmland, e.g. in semi-arid areas of Gujarat (see for instance Patel and Singh, 2000), or wastelands as in Tamil Nadhu (see Madhu *et al*., 2001). Pareek (1999) lists selections 'Yogesharai', 'PKM', 'T3' and 'TIB' as suitable cultivars for arid zones.

8.3.4 Current constraints

The preliminary studies undertaken by different countries provide ample evidence on the status of germplasm evaluations of tamarind. It is also evident that most of the studies are incomplete and limited to a few locations; neither are they well documented nor catalogued. Lack of secure financial support could lead to loss of accessions used in selecting, and the importance of conserving landmarks in improvement of tamarind needs to be stressed.

A better picture of the patterns of genetic diversity in tamarind could be obtained by biochemical and molecular markers being more effectively used to analyse genetic variation within and between populations. These modern techniques have to be used in combination with other methods of characterisation and evaluation in order to detect adaptive genetic variation. The use of markers could enable the more rapid identification of genetic variation in tamarind.

The majority of accessions held in working collections are not duplicated elsewhere and are prone to destruction by catastrophic events such as fire and hurricanes while natural populations are also being depleted for various reasons. Thus there is the need to develop a national and regional collaborative integrated approach for use linked to germplasm conservation.

8.3.4.1 The need to identify rootstocks

Since selected genotypes will be propagated vegetatively attention also has to be given to rootstock geotypes in the event that materials are grafted. Some research has started to evaluate rootstock genotypes (Sothishkumar and McKeaslin, 2003). Growth after grafting is a suitable parameter by which to characterise genotypes.

8.3.5 Germplasm in other countries

In other countries no formal germplasm collections have been made although in Sri Lanka, a germplasm collection has been initiated at the Plant Genetic Resources Centre, Gannoruwa, Peradeniya and the Postgraduate Institute of Agriculture, University of Peradeniya. Although variation has been detected on fruit quality, pod size, flower colour, tolerance to various environmental conditions and pests and diseases, no formal cultivars have yet been identified.

8.4 Identified cultivars

In India, Thailand and the Philippines, two major types of tamarind are recognised based on the sweetness of the fruit pulp. These are ‘sweet fruit’ and ‘sour fruit’ types. Sometimes the cultivars are differentiated by pulp colour, which may be red or brown (Plate 15). The red coloured pulp is considered to be of superior quality due to its sweet taste. Generally unselected tamarind cultivars are grown and these vary in fruit size and degree of sweetness. In the Philippines eight recognised cultivars are grown by farmers while over 50 are grown in Thailand. Specific sweet and sour cultivars also exist in the east and northern parts of Uganda and Kenya. Table 8.3 lists the most popular improved cultivars in those countries.

Table 8.3 Selected tamarind cultivars

Country	Cultivar
Thailand	Muen Chong, Sri Tong, Nam Pleung, Jac Hom, Kun Sun, Kru Sen, Nazi Zad, Sri Chompoo
Philippines	Cavite, Batangas, Bulacan, and Laguna
India	Prathisthan, Periyakulam (PKM 1), Urigam

8.5 Genetic conservation

Although wild and naturalised tamarind is widely available, some genetic erosion is occurring in most areas due to rapid deforestation resulting from rural development and urbanisation. Population pressure on limited ecosystems and resources is causing rapid and damaging shifts in land use patterns with increasing areas being planted with perennial cash crops. Selective felling of individual trees of tamarind for timber and fuelwood in rural locations can also cause genetic erosion as farmers' selections are lost.

Instances of loss of germplasm have been reported in different countries. The development of the Mahaweli River Development Project in the dry zone of Sri Lanka removed 200,000 ha of dry zone forest in which tamarind thrived in forest ecosystems. In southern Malawi deforestation is reported to be the major cause for the loss of wild and semi wild fruits trees such as *Tamarindus indica, Ficus* spp., *Annona senegalensis* and others. Here, tamarind is reported to be one of the most important indigenous fruit trees for consumption and sale in the Mangochi district of Malawi, but the numbers of trees are decreasing at a high rate and becoming rare: this is now of concern to the local communities. (Maliro and Kwapata, 2002).

A strategy for such fruit trees should be promoted to include conservation, enhanced domestication and systematic germplasm maintenance in working collections to back up improvement activities.

Options for genetic conservation include *ex situ* management, one of the easiest and most economically and socially acceptable method for tamarind conservation (Singha, 1995). In this way, phenotypically superior germplasm is collected from different regions and multiplied through vegetative propagation and maintained in clonal orchards. The totally inadequate *ex situ* conservation collections are given in Appendix II. Seed germplasm banks can be maintained since seeds may be stored under conservation conditions for long periods. However this is heterozygous material and cannot quickly replicate superior phenotypes. Conservation through utilisation is likely to be most successful method since access to trees provides a sustainable incentive for local farmers to conserve them. Hence there is a need to develop strategies for on-farm conservation (including home gardens).

On-farm conservation should be linked to the establishment of protected areas as practised for the conservation of forest genetic resources (Collins *et al*., 1991). This method of *in situ* conservation has inherent problems for tamarind as individual trees are often grown in villages, roadsides, boundary plantings etc. and not in mixed stands as in natural reserved forests. Protected areas and on-farm conservation can be linked to wood lots or patches of trees that grow in different locations.

8.6 Conclusions

At present attempts are being made in different countries to collect germplasm to improve tamarind to meet foreseen commercial needs and to support rural development. It is necessary to support the maintenance of existing germplasm collections and to expand most of these. A regional collaborative arrangement is likely to be required to maximises efforts in collecting and maintaining tamarind genetic resources. Additionally, a strategy needs to be developed to support germplasm conservation and use and for this to be translated into official policies.

Since considerable variation exists in the species there are enormous opportunities for varietal improvement. Tree improvement holds the key for boosting the yield of the plantations and it can utilise the genotypes which are packed with desirable characteristics like fast growth, good tree form, high yield and resistance to pests and diseases etc. (Radhamani *et al*., 1998). It is necessary to understand the magnitude of the genetic variation for yield and its components to adopt an effective breeding programme for its improvement (Holden and Williams, 1984; Ram, 1997). In spite of this widely accepted recognition, the use of tamarind germplasm collections for tree improvement is limited and opportunities are not being fully exploited (Gill, 1984; 1985).

An updated list of institutions with collections of tamarind germplasm, individuals/institutes involved with research on tamarind, and seed suppliers are given in Appendices I, II and III, respectively.

Chapter 9. Harvest, Postharvest and Processing

K.V.R. Ramana, B.A. Prasad and P. Vijayanand

9.1 Introduction

Harvesting of tamarind fruits commences when the pods feel brittle by pressing. Trees grown from seed may take more than seven years to start bearing and up to 10 or 12 years before an appreciable crop is produced. Unselected trees in India are late bearers and may take 10-14 years before fruiting. Well-tended trees grown in open areas will come into bearing early, in about seven years or less. Grafted trees will however come into bearing several years earlier. It is reported that in Madagascar trees will begin to bear in the fourth year and in Mexico in the fifth year. The sweet cultivars planted in Thailand bear in about 3-4 years. These differences in the onset of bearing may be associated with genetic or ecological factors. According to Coronel (1991), plantations in the central delta of Thailand become dwarfed due to the high water table, which prevents the growth of a deep root system. Such stress conditions lead to early bearing. In all cases, pod yield stabilises at about 15 years and continues for up to 50 or 60 years.

Tamarind seed pods fill at maturity. The pulp becomes brown to reddish brown and the testa becomes brittle and cracks easily. The pulp dehydrates and becomes sticky and the seeds become hard, dark brown and glossy. Mature fruits have brown shells, while immature ones are green. Tapping them with the finger can help to identify the mature fruits. A hollow, loose sound will be produced as the pulp shrinks with maturity and the shell becomes brittle. At this stage the fruits are mature and ready for harvesting. However, it is not always easy to determine whether the fruits are ready for harvesting, as the testa colour only changes slowly as the pods mature. Individual fruits on the same tree also mature at different times making it necessary for the harvesting to be done selectively.

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. The seeds, when used as a food, are roasted and soaked in water until the hard seed coat splits and comes off. The cotyledons are then boiled and eaten.

9.2 Harvesting stage

In the Philippines fruits are harvested at two stages, green for flavouring and ripe for processing. The fruits of sweet types are also harvested at two stages, half-ripe and ripe. At the half ripe stage the pulp is yellowish green and has the consistency of an apple, particularly in the case of sweet forms. 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 ripe fruits are harvested by shaking the branches and the pods are collected on a mat. Sweet tamarind pods fetch a high price both in local and foreign markets and are carefully harvested by hand picking. Sometimes bamboo ladders are used to pick the fruits. If the whole fruit is marketed, both sweet and sour types should be harvested by clipping to avoid damaging the pods (Coronel, 1991). The use of poles in picking is not desirable as knocking can cause damage to the pods.

Generally, the fruits are left to ripen on the tree before harvesting, so that the moisture content is reduced to about 20%. Mexican studies reveal that the fruits begin to dehydrate 203 days after fruit set, losing approximately half of the moisture. When the fruits are left unharvested they may remain hanging on the tree for almost one year after flowering and eventually abscise naturally. Sometimes they remain on the tree until the next flowering period (Chaturvedi, 1985).

9.3 Yield

The yield of tamarind varies considerably in different countries, depending on genetic and environmental factors. Feungchan *et al*. (1996 a) reported that the fruit yields are influenced by environmental and genetic factors, but the age of the tree is not correlated with fruit yield. The size of the tree is obviously a factor however, and older trees which have had many years to mature, would be expected to be larger and so produce a greater yield. Age of bearing is important in relation to profits. Reports of very long juvenile periods over 4-10 years are probably because they were recorded on unselected materials.

Usha and Singh (1996) reported that cross-pollination results in higher fruit set and retention in tamarind than when open or self-pollinated. Bees are known to pollinate tamarind, and bee farming could provide additional income to farmers. Fruit set is influenced by environmental factors, such as age and size of shoots, carbon : nitrogen ratio and the hormonal balance under which the trees are grown. Due to the influence of these factors, high seasonal and annual yield variations can be expected.

Tree to tree variation is widely observed in growth and yield. Pod yield is sometimes cyclic, with bumper yields in every third year (Jambulingam and Fernandes, 1986). Jambulingam *et al.* (1997), quoted from Rao *et al.,* (1999) presumed that this was due to the high demands of flowers absorbing much of the available nutrients and thus weakening the physiological condition of the tree. The tree then needs to recover for a couple of years before reaching peak performance again.

Presently, fruits are harvested from untended trees and wild types, although in Thailand a few sweet tamarind orchards have been established recently. A young tree yields 20-30 kg fruits per year, while full grown trees of 20 years of age are known to yield 150 -200 kg/tree/year or 12-16 t/ha (NAS, 1979; Chapman, 1984). A full-grown tree is reported to yield about 180-225 kg of fruits per season (FAO, 1988). In India, the average production of tamarind pods per tree is 175 kg and of processed pulp is 70 kg/tree (Kulkarni *et al.*, 1993). The best yielding elite trees in Bangalore have pod yields ranging from 250-350 kg/tree and pulp yields of 100-175 kg/tree (Kulkarni *et al.*, 1993). Yields up to 170 kg/tree/yr of prepared pulp have been reported in India and Sri Lanka (Coronel, 1991). Rao (1995) reported that Periyakulam 1 (PKM1), an improved cultivar in Tamil Nadu, yields about 263 kg/tree, 59% more than unselected cultivars. In India, Jambulingam and Fernandes (1986) reported very high yields of 500 kg/tree/year, while Hanamashetti and Madiwalar (1992) estimated yields of 450-800 kg/tree/year. In the Philippines, 200-300 pods (about 100 kgs) per tree is considered a good yield. Based on this yield, 100 trees per ha will yield about 8-9 tons of prepared pulp (Coronel, 1991). Under average conditions the pod yield ranges from 80-90 kg/tree/year. As pod yield starts to decrease after about 50 years, older trees are sometimes harvested for charcoal or fuelwood (Jambulingam and Fernandes, 1986)

9.4 Storage

Fresh fruits are often dried using small-scale dehydrators, however in most countries rural households dry pods in the sun. The shells, fibres and seeds are then removed and the pulp stored in plastic bags or earthenware pots. (see Plate 16).

The dry ripe pods can easily be cracked and the pulp and fibres separated from the broken shells. The pulp is then processed by peeling and removing the fibre strands from the pulp. After separating the pulp from the fibres, 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 Thailand, the pulp is mixed with salt and compressed and packed in plastic bags to exclude air for storage. Each bag weighs about 5 kg and these are repacked in boxes for transport to distant markets.

In most of the tamarind growing countries pulp is pressed and preserved in large masses and sold in small shops and markets by weight. Sometimes the cleaned pulp is compressed and packed in palm leaf mats or gunny bags for storage and marketing. 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. When tamarind is processed for shipment to large-scale processors, the pulp is removed from the seeds, layered with sugar and then covered with boiling sugar syrup.

In Sri Lanka, the harvested pods are dried in the sun for 5-7 days to bring all fruits including the half-mature fruit to the fully ripe stage. The pods are then cracked to separate the pulp. The pulp with the seed is spread on thick polythene sheets and dried in the sun for 3-4 days to remove excess moisture and prevent the growth of moulds. The dried pulp is mixed with salt and packed in clay pots for storage. These pots are usually kept in a dry place, preferably in the kitchen. Through this process tamarind can be stored for about a year, after which the colour changes to dark brown or black and changes in flavour occur (Samarakoon, 1999, personal communication). Although pulp is stored with the seeds intact in rural households, seedless pulp is stored in plastic bags in retail shops (Gunasena, 1997).

These methods are manual and crude and tend to be very labour intensive and inefficient. Mechanical methods of extracting pulp have been reported (Benero *et al.*, 1972) and a tamarind dehuller has also been designed and developed at the Post Harvest Technology Scheme (ICAR), UAS, Bangalore, India. The machine has a hulling capacity of 500 kg/h, with hulling efficiency of 80% for large fruits and 58% for small fruits (Ramkumar *et al*, 1997 quoted from Rao *et al.,* 1999). Studies carried out by the same group on storage media indicated that the pulp loss percentage during storage was very low in black polyethene and plastic compared to phoenix mat and metal.

The quality and condition of the pulp and the selling price in the market are often related to the care taken during storage. The freshly prepared pulp is light brown in colour, but darkens in storage. Generally under dry conditions the pulp remains good for about one year, after which it becomes almost black. The pulp also becomes soft and sticky as pectolytic degradation takes place and moisture is absorbed, especially in humid weather (Lewis and Neelakantan, 1964 a; Anon, 1976). Continuous storage for long periods under poor conditions, such as exposure to extremes of temperature and humidity, is a problem because of changes in colour which take place from brown or yellowish brown to black (FAO, 1989).

Feungchan *et al*. (1966 f) attempted several methods to prevent change of pulp colour including powdered salt, steam, sodium metabisulphite, sun drying, hot air incubation and cold storage. Cold storage of pulp in transparent containers at 0^o C, and mixing powdered salt at 10% by weight in a transparent container are satisfactory ways to prevent the colour change in tamarind. However, the use of salt and storage in a transparent container is considered best due to its ease of handling, and it is more cost effective than cold storage.

The pulp can be stored in a cool, dry place for three to six months without much attention. In some places in India salted (10%) pulp is trodden into a mass and made into balls, exposed to the sun or steamed for a short time, and then exposed to the sun and dew for about a week (Shankaracharya, 1998).

Various methods for prolonging the storage life of the whole fruit and pulp have been developed. According to Chumsai-Silvanich *et al*. (1991), steaming the tamarind fruit for five minutes, followed by drying in a hot air oven at 80^o C for two hours and storing in plastic bags at room temperature is a suitable method. Using this method, the fruits can be stored for four months without any deterioration in quality. Similarly, steaming the pulp for 20 minutes, followed by drying at 60^o C for 2.5 hours and packing in clear plastic bags will allow storage for three months. Freshly harvested fruits can be stored for a few days in a refrigerator or freezer. Drying is the best way to store small amounts of tamarind pulp (Campbell and Campbell, 1983). Freshly harvested tamarind pulp can be preserved well for 4-6 months by packing in high-density polythene bags and storing below 10^o C in a dry place. Lewis and Neelakantan (1964 a) reported that by mixing the shelled tamarind fruits with a small amount of water and passing them through a pulper, the residual seeds, fibre and other extraneous materials can be removed. Drum drying this homogeneous pulp and compressing it in moulds gives cheese-like blocks which are ideal for utilisation by industry.

Refrigerated storage of the freshly harvested, deseeded, semidried ripe pulp is highly recommended in order to retain the attractive brownish red colour of the pulp for long term storage and marketing. In areas where the tamarind tree is an alternate bearer, traders purchase tamarind in a good crop year for stocking in cold storage, for sale in the subsequent year (*Indian Agriculture*, 2003).

Deseeded pulp packed in 150 gauge poly bags of 5 kg capacity (fresh commercial sample) can be stored under refrigerated conditions (4-6° C; RH 75-80%) for up to six months and retain an acceptable reddish brown colour (Puranaik *et al*, 2004). Recent studies carried out at Tamil Nadu Agricultural University, Coimbatore, India, indicated that the freshly harvested deseeded tamarind pulp can be stored for up to 330 days under refrigeration at 4 ± 2^0 C when vacuum packed in 800 gauge poly bags without any colour change in the pulp right from the initial stage of storage (Nagalakshmi and Chezhian 2004).

Semi-dried tamarind pulp has a moisture content ranging from 17-20%. Tamarind pulp packed in aluminium foil with vacuum, aluminium foil, metallized polyester, polyethylene and polypropylene pouches and stored at 27° C and 65% RH for 180 days retained overall quality. However its colour values were poor at higher temperatures.

Enzymatic browning was studied by Kotecha and Kadam, (2003 b). The browning increased with increase in storage time. Polyphenol oxidase (catechol oxidase) and catalase activities increased for up to 120 days and decreased slightly after 180 days of storage. Peroxidase activity and non-enzymatic browning increased during storage.

9.5 Processed products from tamarind

The commonly available market samples of tamarind pulp usually contains extraneous matter such as seed, dust, fibre, etc., and hence can be unfit for various culinary preparations. Value addition is of immense benefit for traders and consumers. Therefore, processed products from tamarind can meet the requirements of consumers for convenience and ready to use. Tamarind is used for the preparation of various processed products and some examples of value additions are cited below.

9.5.1 Tamarind beverage

Tamarind fruit pulp is used for the preparation of beverages in different regions. Good quality ready to serve beverage, syrup and concentrate can be prepared with a shelf life of six months at ambient storage (Kotecha and Kadam, 2003 a).

Tamarind pulp was treated with pectolytic enzymes and the extract obtained was used for the preparation of flavoured RTS tamarind beverage. The carbonated tamarind beverage having 12.5% juice, 16°Brix and 0.4% acidity was found to be highly acceptable for up to two months of storage at room temperature (Lakshmi *et al*., 2005).

9.5.2 Foam mat drying of tamarind pulp

Drying of tamarind pulp by foam mat drying using different foaming agents was reported by Vernon-Carter *et al*. (2001). The foaming agent viz., mequite gum, ovalbumin and a low molecular weight surface active blend were hydrated to 50% (w/w) solutions and added to the samples either singly or in combination. It was found that the mesquite gum+surface active blend, and ovalbumin+surface active blend, ovalbumin+mesquite gum resulted in acceptable flavours.

9.5.3 Tamarind juice concentrate

A process for the preparation of tamarind juice concentrate was developed by Central Food Technological Research Institute, Mysore, India. The process involves extraction of tamarind juice and concentrating the juice in a vacuum evaporator to total soluble solids of 70°Brix. The tamarind concentrate is shelf stable at room temperature and can be diluted and used in various food preparations.

Tamarind juice concentrate exhibited Newtonian flow behaviour up to 19°Brix and pseudo plastic nature at higher than 23°Brix obeying the power law relationship. The flow behaviour index for concentrate of 23°Brix was 0.747 and 0.625 for concentrate of 28-62 ° Brix.

9.5.4 Tamarind seed products

(i) Tamarind seed polysaccharide

Tamarind seed polysaccharide is used as a gelling, thickening or stabilising agent in foods in Japan. Tamarind kernel powder is now extensively used for sizing fabrics in textile industries. There is wider interest over the past few years in the use of tamarind seed polysaccharide extracts in the food industry (Salazar *et al*, 2002).

(ii) Antioxidants from tamarind seed coat

Extraction of antioxidant compounds from the seed coat of sweet Thai tamarind was reported by Luengthanaphol *et al*., (2004). The antioxidants were extracted by supercritical fluid extraction and by solvent extraction using ether or ethyl acetate. The mixture obtained by solvent extraction with ethanol showed epicatechin yield of 150mg/100g and the highest antioxidant activity in terms of peroxide value as compared to the supercritical fluid extraction.

Crude tamarind seed coat extracts were stable following heat treatment at 100° C for two hours. Antioxidative activity of the extracts was lower at pH 5.0 than at pH 3.0 or 7.0.

Chapter 10. Economics of Production, Marketing and Trade

K.V.R. Ramana, B.A. Prasad and P. Vijayanand

10.1 Introduction

Statistics relating to tamarind production, marketing and exports are exceedingly patchy. What figures are available are not always reliable. This chapter uses illustrations only to support the known potential for the crop and to highlight trends in demand.

10.2 Economics of production

Information from the Periyakulam Research Station, Tamil Nadu, India shows that the cost involved in production is mostly for field labour and the purchase of seedlings or grafts. There is no income in the first three years but intercropping with annual crops can compensate for the labour and other costs. Trees will begin to bear from the fourth year if they have been vegetatively propagated and have a pod yield of 40 kg/tree giving a net profit of Indian Rs 14,000 per hectare. When the trees reach maximum bearing at 10 years, a yield of about 100 kg/tree could be harvested with a profit of Rs 38,000 (Table 10.1).

Table 10.1 Income from a tamarind plantation, Periyakulam Research Station, Tamil Nadu, India. Estimates are based on 90 trees per hectare and the rate of the tamarind fresh pulp @ Rs 10/- per kg

Year	Investment (Rs)	Tamarind per tree (kg)	Yield per ha (kg)	Income (Rs)	Net Income (Rs)
1st	1500/-				
2nd	1000/-				
3rd	1000/-				
4th	2000/-	40	1600	16 000	14 000
5th	2000/-	50	2000	20 000	18 000
6th	2000/-	60	2400	24 000	22 000
7th	2000/-	70	2800	28 000	26 000
8th	2000/-	80	3200	32 000	30 000
9th	2000/-	90	3600	36 000	34 000
10th	2000/-	100	4000	40 000	38 000
11th year and above	2000/-	100	4000	40 000	38 000

Source: Rao (1995)

The profitability of seedling orchards vs clonal orchards established on farmers' land was looked at by the Genetics and Plant Breeding Department of the University of Agricultural Sciences, Bangalore, India (Kulkarni *et al*., 1993). As shown in Table 10.2, the clonal establishment was highly profitable because of high net returns and low establishment costs compared with seedling orchards.

Table 10.2 Profitability of seed vs clonal orchards/ ha

Nature of orchard	Total cost (Rs)	Total returns (Rs)	Net return (Rs)
Seedling orchard	5600	44 200	38 600
Clonal orchard	5000	51 950	46 000

Source: Kulkarni *et al.* (1993)

The orchards established using clones are of uniform size, the fruits are of high quality and the trees yield well. These trees also come into bearing earlier than seedling orchards, but their life span may be shorter. Hence, use of selected cultivars to establish small or medium scale orchards is economically viable.

Based on information from the Periyakulam Research Station, each tamarind tree will give an average yield of 100 kg of fresh tamarind pulp per year at maturity. From the fourth year, yields increase until the tenth year when it stabilises. Financial and energy inputs are highest in the first year (Rao and Singh, 1996).

In Cumbum, Madurai district, Tamil Nadu, individual farmers are reported to plant large areas of local tamarind trees with yields up to 70 kg tamarind pulp per tree in the fourth year. This indicates that tamarind can be grown commercially even by small-scale farmers. It is also necessary to encourage farmers to grow selected cultivars, as high yields and more economic benefits could be assured. If plantations are to be established on marginal lands unsuitable for production of other crops, reduced yields have to be factored into cost-benefit analyses.

10.3 Production figures

Tamarind production is expanding and although the production should be substantial statistical records are not given for tamarind. Instead, it is included with 'other' species of exotic fruits or spices and as its production is not monitored by any agency, no data on area, production and yield of tamarind is available. Even the trade is so unorganised that traders are also not able to provide any information.

Tamarind in India is mainly produced in the States of Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, Kerala and Uttara Pradesh. The crop from Karnataka and Andhra Pradesh arrives in the market in January, that from Maharashtra arrives in February and from Madhya Pradesh and Uttara Pradesh at the end of February.

Sour types of tamarind comprise about 95% of total world production. India is the major sour tamarind producer in Asia. Its annual production is about 300,000 tonnes. About 20,000 tonnes of TKP is also produced annually in India, but this could be doubled through improved post harvest and processing techniques. Annual returns from tamarind seed powder are estimated at Rs 16 -17 million.

Thailand is the second largest producer of tamarind in Asia of which 30% is the sweet type. This is gaining status as a small-scale plantation crop. Thailand also produces the sour type of tamarind and although the sour type dominates the sweet type is receiving more demand. Sweet tamarind is grown on a commercial scale for export both in the fresh and processed forms. There is good demand for it as a dried fruit, which is packed into boxes weighing 10-15 kgs and sold in open markets in Thailand. The fresh pods are also valued and large sweet pods are highly priced, particularly during the off season (Yaacob and Subhadrabandhu, 1995). During the 1990s the tamarind trade expanded with production in 1995 at 140,000 tonnes (Figure 10.1). The ratio of non-bearing area to total production suggests that production is already expanding.

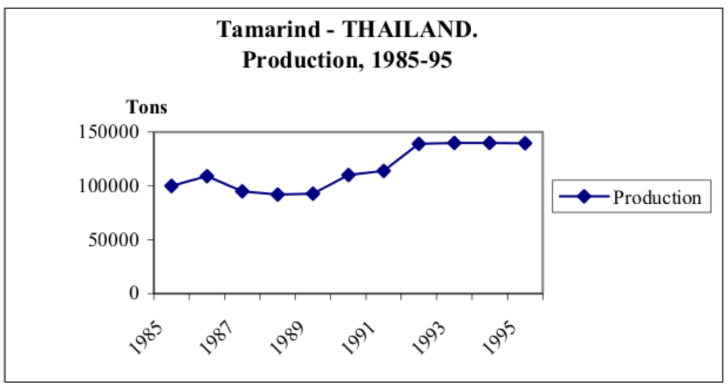

Figure 10.1 Tamarind production in Thailand
(Source: Vinning and Moody, 1997)

Sri Lanka and Indonesia are also large tamarind producers in Asia, and in South America Brazil and Venezuela are sizeable producers. Unfortunately statistics are unavailable for these countries but their production is not thought to match that of India and Thailand.

National production in Australia is less than 6 tonnes, which reflects the cultural mix of people residing in the country as tamarind is primarily consumed by people of Asian origin. Most of the production is from Queensland and available from May-September.

Costa Rica is a relatively small scale producer. It exports small quantities of tamarind to North America, though production is increasing (Figure10.2).

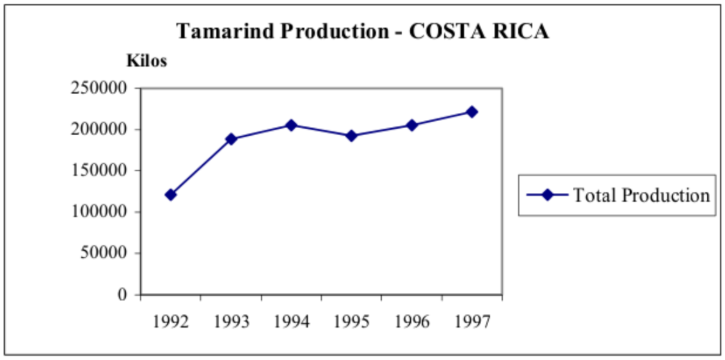

Figure 10.2. Tamarind production in Costa Rica

In Puerto Rico, there is no commercial production of tamarind, but the fruits grow wild throughout the island and in home gardens. The estimated production of tamarind in Puerto Rico in 1977 was 23 tonnes (Salkukhe and Desai*,* 1984). Like Puerto Rico, most other tamarind growing countries have no commercial production, and fruits are collected from trees that grow in the wild or in home gardens for household level processing and consumption, with any excess being marketed.

Other than local collection and sale of tamarind in Africa, in general there is no commercial production. Tamarind has not gained the same importance in Africa as it has in Asia. Introduced Indian and American cultivars are currently more productive than African ones.

10.4 Employment

The production, processing, sale and use of tamarind products create employment opportunities for people in producing countries. At present tamarind is considered to be a Minor Forest Product (MFP) classified in India by the National Commission on Agriculture (quoted in Sekar *et al.*, 1996) together with fibres and flosses; grasses and bamboo canes; essential oils; tans and dyes; gums, resins and oleoresins; drugs; spices; insecticides; leaves; edible products; lac and its products, and miscellaneous products. Most of these products have traditionally been collected, processed, consumed and traded by people in and around forest areas for generations. At a national level, over 50% of forest revenue and 70% of forest exports comes from MFPs, they provide 50% of income for 20-30% of rural people in India. Tamarind is marketed mainly by rural communities and forms a significant part of their income. The annual quantity and earnings from non-wood forest products, including tamarind, per family in tribal villages of South Bihar and South West Bengal is reported to be substantial (220 kg of tamarind earning Rs 514 (Rao and Singh, 1996). Therefore, better cultivation of tamarind and improvement of processing technologies will enhance the employment opportunities of rural people in the producing countries.

The importance of growers understanding the need for a business plan was shown in Thailand where training on all aspects of production and marketing was provided to 120 farms at a community business level. Business planning, group management and financial accounting management rapidly increased (Treewannakul *et al*, 2004).

10.5 Marketing

Tamarind fruit pulp is manufactured and marketed wherever tamarind is cultivated, however much of the trade is local, carried out in small towns and villages. 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 producing countries unimproved trees are cultivated. The exception is the recent development of cultivars in India of the sweet types growing in Southeast Asia, where there is an emerging interest in the crop for the fresh fruit trade.
- Fresh fruits of the sour type have village level markets yet the fruits are often not collected because of low demand and the low prices received by collectors. Often producers are exploited by middlemen.
- Most of the fruits and seeds go to waste due to lack of technologies for processing and storage. Available technologies have not been disseminated among growers in different countries.
- Processed pulp is of low quality and does not meet the standards of the international market.
- Alternate low cost processing technologies are not readily available.
- Many of the products presently available are restricted to domestic markets of producing countries and have not reached international markets.

- Most of the exports are from only a few of the major producing countries and are limited to fresh fruits, pulp, seed kernel powder and paste, of which the pulp and seed kernel powder is used for the manufacture of drugs, industrial applications, and culinary purposes. Its industrial potential is not fully exploited.
- Tamarind is often considered to be an ethnic food. In importing countries it is used by Asian consumers with little evidence of crossing over to other ethnic groups.
- Lack of both local and international market information restricts expansion of crop and product diversification.

If the production were improved and international markets created for fresh and processed products, then production could be increased to make it more attractive and profitable.

10.5.1 Domestic marketing

Tamarind is a delicacy in the producing countries and is used widely 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 fairs. Intermediaries collect the products from farmers and sell them to retailers or processors. The collectors receive low prices, hence much produce is not harvested even when there is increasing demand in towns and cities. Establishment of small-scale plantations would be more attractive to both collectors and buyers (see Plate 17).

Commercialisation is constrained because there is widespread scattered planting of trees and the fruit quality may be poor. Even in Thailand, where small-scale commercialisation has begun, fruits from household plantings have been competing with commercial production. There are no established fair-price marketing mechanisms for tamarind in any of the major producing countries, the only exception being the fruits produced for the fresh fruit market by farmers in Thailand.

In Indonesia, the Philippines and Thailand, in South Asia, and in some African and Central American countries, the major products sold in the local markets are juice, chutney, sauce, paste, fresh fruits and pulp. In the Philippines fresh fruits are harvested, placed in baskets or kaings or tied into bundles and sold in rural and urban markets by volume or weight (Coronel, 1986). The price for a kilogram is about P 15. In Thailand fruits are also sold fresh, with sweet varieties (B 37/kg, US$ 0.95/kg) earning more than double the price of the sour varieties (B 8.66/kg). The fresh fruits of the sweet tamarind cultivars are sold by weight for direct consumption. In India, processed tamarind products are sold in rural markets and in supermarkets in cities. The major products sold locally are tamarind pulp powder, paste, chutney and fresh pulp. Similarly, processed products are popular in Sri Lanka and fresh pulp itself is wrapped in polythene bags and sold in retail shops. Tamarind chutney is also available in Sri Lankan supermarkets and tamarind-lime pickle has been promoted in Sri Lankan markets by the Marketing Department. In Australia, fresh fruits are packed in 15 kg cartons and sold through wholesalers and Asian groceries. The wholesale price per kilogram is about $A 3-5 per carton.

Marothia and Gauraha (1992) studied the marketing mechanisms of minor forest products (MFPs) in the Raipur district, Madhya Pradesh, India. They found that 80% of the villagers were engaged in the collection of MFPs, including tamarind, and earned their livelihood by consuming and marketing these products. A well-organised traditional marketing system exists in the district. Products collected by villagers were procured by the tribal agent, and the primary wholesaler and retailer. The secondary wholesaler and the commission agents who visit the village at their weekly markets then purchase these. The primary retailer will often purchase the products and sell them to the secondary wholesaler at the weekly markets. In the case of tamarind fruits, 14.4% of the total collection of about 24 tonnes is consumed locally while the balance of 83.3% is market surplus.

In BR Hills region of Karnataka, India, Vivekananda Girigina Kalyana Kendra (VGKK), a non governmental organisation (NGO) is actively working to improve benefits for tribals in that region. The NGO helps in production and marketing of deseeded tamarind in the form of tamarind blocks (0.5-1 kg) wrapped with polythene film.

The total quantity of starch powder (39 tonnes) produced by the villagers was purchased by the tribal agents and sold at the weekly markets to the secondary wholesalers. In this marketing chain, the actual price received by the collector per kilogram was Rs 700.00 while that of the primary wholesaler/ retailer was Rs 1100.00, leaving a margin of 36%. The cost of marketing increased with the length of the marketing channel and it was also evident that the secondary wholesalers sold the produce to the leading trade centres in other States or for export directly. In this study it was clearly shown that neither the collectors nor the consumers benefited in the price spread due to unorganised marketing. The only beneficiaries of the traditional marketing channel were the intermediaries. The marketing system in the rest of South and Southeast Asia operates similarly through the aegis of middlemen. This shows the need for organising the domestic marketing system and encouraging the cultivation and processing of tamarind.

In order to minimise exploitation of poor people and improve marketability Marothia and Gauraha (1992) suggest that village level marketing institutions may establish small-scale collection centres in the villages. Public, private and co-operative units may then be established. Policy and intervention will not only reduce export of raw forest products to other States but also provide an opportunity to develop a network of processing units at a local level for manufacturing finished products. This will increase State revenue and per capita income of the co-operatives. The capital earned by the co-operatives may be ploughed back into the area to build up social capital infrastructures. Marotia and Gauraha (1992) believe that in the long run minor forest products may emerge as an organised sector and remove forest dwellers and other rural poor from the exploitative market.

In the Kolli Hills region of Tamil Nadu, India, the MS Swaminathan Research Foundation in Chennai, an NGO, organised training programmes for tribal people and trained self help groups in post harvest practices to tap the indigenous resources such as tamarind (as well as amla and pineapple) to get monetary benefits.

In all producing countries there is a domestic market for tamarind. To strengthen local markets it will be necessary to establish the size of the market, target consumers and the type of products in demand. Therefore, efforts to find potential markets for tamarind products will be useful to exploit its potential.

There is evidence that marketing implications are just beginning to be looked at. For instance, Reddy *et al.* (2001) analysed the price behaviour of tamarind in the Ananitspur and Chittour districts of Rogalseema region of Andhra Pradhesh in India for the period 1990-1999. Several variations in prices and secular trends provide pointers for growers supplying the markets.

10.5.2 International marketing

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 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 the quantity available and the country. Tamarind is very much an ethnic food, hence importing countries tend to have large populations of Asians, Africans and West Indians. In most countries, tamarind exported in fairly small quantities is categorised with 'miscellaneous products' in customs reports. This makes it difficult to obtain representative and detailed information on the international trade of tamarind. The information in this chapter however, indicates an increase in the import/export of tamarind over the past decade and a rising demand for the products.

10.6 Exports

India is the foremost exporter of tamarind and its products. Exports of fresh tamarind during 2001-2002 reached 1434.15 MT valued at about Rs 24 million. The importing countries are mainly Pakistan (170.6 MT, valued at Rs 1.8 million) followed by UAE (232.05 MT valued at Rs 4.285 million), Japan and Yemen. The other importing countries include Germany, France, Malaysia, United Kingdom, Italy and Bangladesh.

India exports tamarind in different forms i.e., fresh, dried, powdered, paste and seed form. Exports of tamarind in different forms are given in Tables 10.3-10.10.

Table 10.3 Export of fresh tamarind from India

Country	2000-2001		2001-2002	
	Quantity (Metric tons)	Value (Rs million)	Quantity (Metric tons)	Value (Rs million)
Australia	0	0	5.22	0.103
Bahrain	0	0	3.80	0.084
Bangladesh	133.70	1.775	0	0
Belgium	40.00	0.505	0	0
Djibouti	24.50	0.410	0	0
Egypt	191.50	4.364	231.00	5.160
Ethiopia	7.00	0.170	0	0
Germany	14.44	0.428	0	0
Indonesia	20.00	0.187	0	0
Italy	20.00	0.207	0	0
Japan	6.40	0.139	0	0
Korea	0	0	10.08	0.142
Kuwait	23.50	0.518	24.54	0.882
Malaysia	402.93	4.023	152	1.262
Netherlands	40.00	0.492	20.00	0.260
Pakistan	648.42	8.867	170.6	1.805
Saudi Arabia	116.14	1.631	146.98	1.579
Singapore	143.23	1.693	43.15	1.299
Sri Lanka	2.00	0.060	0	0
Syria	148.00	3.170	230.5	4.500
UAE	219.12	3.580	232.05	4.285
UK	36.56	1.208	21.68	0.431
USA	0	0	29	0.671
Yemen	41.15	0.505	113.55	1.525
Total	2278.59	33.932	1434.15	23.988

Source: *Indian Agriculture* (2003)

Table 10.4 **Export of dried tamarind from India**

Country	2000-2001 Quantity (metric tons)	2000-2001 Value (Rs million)	2001-2002 Quantity (metric tons)	2001-2002 Value (Rs million)
Australia	0	0	11.20	0.424
Bahrain	50.10	1.304	64.24	1.548
Bangladesh	196.47	2.488	48.50	0.406
Belgium	0	0	79	4.629
Canada	12.60	0.48	34.86	1.314
Djibouti	70	1.313	135.25	2.665
Egypt	843.5	19.329	412.6	12.295
Ethiopia	40	0.839	3.5	0.637
Germany	20.58	0.309	0	0
Hong Kong	1	0.047	20.11	0.252
Indonesia	171.4	2.271	34	1.479
Israel	28	1.276	0.69	0.030
Italy	40.25	0.891	21	0.988
Jordan	61.20	1.319	39.6	0.785
Korea DPRP	17	0.891	15	0.849
Korea RP	0	0	33.06	1.598
Kuwait	26.9	0.652	61.94	1.546
Latvia	88	2.018	0	0
Malaysia	429.09	6.085	4.46	0.271
Mali	86	1.52	0	0
Netherlands	61.05	0.901	60	0.787
Oman	80.95	2.444	87.01	2.854
Pakistan	137.8	1.760	172.19	1.638
Saudi Arabia	1199.48	25.478	630.07	12.974
Singapore	161.47	3.921	144.69	3.987
South Africa	62.4	1.317	6.25	0.204
Sri Lanka	1.50	0.065	0	0
Switzerland	80	0.897	0	0
Syria	311.7	7.111	127.8	2.569
UAE	1847.41	42.273	1482.59	33.16
UK	220.76	7.675	304.84	9.296
USA	226.51	8.236	212.7	6.237
Yemen	498.02	6.672	348.43	4.245
Total	7071.14	151.782	4595.58	109.667

Source: *Indian Agriculture* (2003)

Table 10.5 Export of tamarind flour meal from India

Country	2000-2001 Quantity (metric tons)	2000-2001 Value (Rs million)	2001-2002 Quantity (metric tons)	2001-2002 Value (Rs million)
China Taipei	0	0	10.5	0.179
China PRP	20	0.348	0	0
Djibouti	20	0.348	0	0
Egypt	0	0	20	0.892
France	0	0	20	0.669
Germany	118	1.519	50	1.442
Indonesia	60	2.744	40	1.879
Italy	27	0.304	100	1.056
Korea DPRP	0	0	36	0.578
Korea RP	18	0.244	97.46	1.629
Malaysia	22	0.251	0	0
Netherlands	118	1.565	289.31	4.457
Saudi Arabia	5.68	0.158	0	0
South Africa	130	2.830	0	0
Switzerland	0	0	50	0.841
UAE	0	0	9	0.235
UK	20	0.320	40	0.537
USA	13.40	0.717	45.7	0.914
Yemen	0	0	10	0.220
Total	572.08	11.348	817.97	15.528

Source: *Indian Agriculture* (2003)

Table 10.6 Export of tamarind seeds from India

Country	2000-2001 Quantity (metric tons)	2000-2001 Value (Rs million)	2001-2002 Quantity (metric tons)	2001-2002 Value (Rs million)
Bangladesh	218	1.78	32.5	1.072
China Taipei	0	0	70	1.483
Egypt	52	1.591	0	0
Germany	188	2.499	0	0
Indonesia	186	7.82	100	4.9
Italy	136	1.564	0	0
Japan	348.5	4.844	0.2	0.011
Korea DPRP	0	0	62.83	2.818
Korea RP	2	1.58	0	0
Malaysia	784	8.414	94	1.688
Mali	164	1.696	0	0
Netherlands	100.1	1.341	200.01	3.083
Netherlands Antilles	40	0.558	0	0
Pakistan	371.66	5.804	4.35	0.034
South Africa	72	2.499	0	0
Switzerland	120	1.377	0	0
Syria	21.63	0.540	42	0.866
UAE	83	1.361	204.69	2.426
UK	110.5	1.863	21.8	0.343
Yemen	0	0	55	0.598
Total	2997.39	47.131	887.38	19.322

Source: *Indian Agriculture* (2003)

Thailand is also a large exporter of tamarind with figures in 1999 reaching 7,006.07 tonnes and a value of B 155.97 million (Department of Agricultural Extension). Exported mainly as fresh fruit, the major importers are Singapore, USA, United Kingdom, Pakistan, Malaysia, South Africa, Kuwait and Bahrain.

Other Asian exporting countries include Sri Lanka, the Philippines and Indonesia. Sri Lanka began to export tamarind products, mainly in the form of pulp, in 1991 when 3360 tonnes were exported to Pakistan, at a value of Sri Lankan Rs 24.5 million. The export quantities gradually increased and reached 6903 tonnes in 1997 at Rs 76.96 million. Although the export quantities have tended to fluctuate, tamarind as an export crop is becoming well established. Sri Lankan exports are mainly to Pakistan (> 90%), UAE (> 4%), Saudi Arabia, India, Canada, Australia, Egypt, Norway, Lebanon and Switzerland (Table 10.7).

Table 10.7 Tamarind exports (mt) from Sri Lanka, 1996-1998

Country	Year					
	1996		1997		1998	
	Mt	Rs Mn	Mt	Rs Mn	Mt	Rs Mn
Australia	6	0.48	-	-	-	-
Canada	-	-	1	0.08	-	-
Egypt	-	-	1	0.07	-	-
India	-	-	20	0.28	21	0.23
Lebanon	-	-	-	-	2	0.27
Norway	0.9	0.09	-	-	-	-
Pakistan	1783	21.99	6589	72.93	841	10.16
Saudi Arabia	-	-	-	-	3	0.39
Switzerland	2	0.11	-	-	-	-
UAE	21	0.37	292	3.60	44	0.88
	1813	23.04	6903	76.96	911	11.93

Source: Sri Lanka Customs Reports, 1996-98

The Philippines have been exporting glazed or crystallised tamarind annually to North America and Guam since 1977, the current export figure is 30,000 kg annually. The Philippines also exports fresh pods of the sweet type to France, Europe and the USA. Indonesia also exports about 20,000 tonnes of tamarind, mainly to Australia (Vinning and Moody, 1997. Figure 10.3 below). The prices have increased by nearly 50% over five years. In the Australian market, the price per kilogram is $A 0.5.

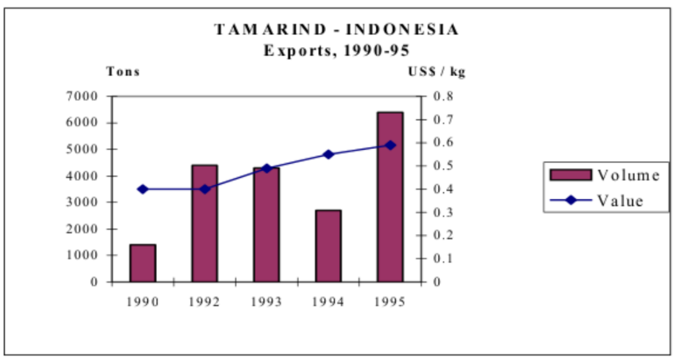

Figure 10.3 Tamarind exports from Indonesia 1990-1995

(Source: Vinning and Moody, 1997)

The major importers of fresh tamarind fruits and products are the United Kingdom, and France for European countries and the USA. Some of these countries import tamarind for the manufacture of pharmaceuticals and some 90,000 kg (88.6 tonnes) of pulp has been imported annually for the drug trade. Most of these supplies are from India and the Greater Antilles. Apart from Thailand and the Philippines, tamarind is also imported to the USA from Nicaragua and many other Central American countries. It is one of the few products that does not require an import permit from the USDA, does not require classification and can be stored for up to six months without degradation of quality.

The United Kingdom imports tamarind throughout the year from four countries, and apart from Asian countries also imports from Brazil and Venezuela. Venezuelan suppliers reach the markets from June to September. The prices per kilogram of sweet tamarind fruits vary from £1.25 in Indian groceries to £2.30 in major supermarkets. The fresh fruit supplies to France are from Thailand and the wholesale prices are consistent, averaging Ff 58-60 per kilogram of sweet fruit. The degree of consistency in the price suggests that the market is very small.

Chapter 11. Current Situation and needs for Research and Technology

J.T. Williams

11.1 Introduction

Although domesticated, tamarind has tended to remain a useful species associated with smallholder farmers and also widely gathered from extensive wild stands. Despite its extensive use it has received minimal research attention. The research has also been somewhat sporadic. Not a great deal has been translated into technology development and even less has been downstreamed to the farmers.

In part this situation relates to the fact that tamarind is a large, relatively long-lived tree species which appears to be easy to cultivate and local demands for the fruits were always satisfied. In fact trees appear to grow unattended in backyards, roadsides or on wetlands and hence tamarind did not become a priority for focused development by governments. Tamarind remains underexploited even though its potential is widely recognised; it will remain so if traditional practices continue to result in poor tree management due to lack of skills in pruning, harvesting and processing of products.

However, the past two decades have witnessed three important advances, namely:

(i) the recognition that exploitation for commerce of wild and primitively cultivated tamarind provides cheap raw material for industrial purposes – and local producers hardly benefit;
(ii) a limited number of cultivars have been developed and, as is the case for sweet tamarind, these can lead to the establishment of more intensive orchards/plantations; and
(iii) an upsurge in the need for agroforestry systems, such as in Asia and Africa and the widespread recognition of the value of tamarind in such systems has resulted in demands for better planting materials, and for better management systems, paying attention to the potential for income generation for resource-poor farmers in all agricultural areas but particularly in the more marginal areas.

11.2 The current situation

The major breakthrough in recent years has been the identification of tamarind types with less acidic pulp, commonly referred to as sweet tamarinds. In Thailand and the Philippines, farmers are growing the sweet types on a limited plantation scale. Selections have been made from among the natural stands growing in those countries. In Thailand, more than 50 sweet tamarind cultivars are grown, while in the Philippines, eight selected cultivars are popular among the farmers. These sweet types have created a resurgence of interest in many countries of the Southeast Asian region and encouraged researchers to undertake studies on tamarind.

The impact of this has been less spectacular in the South Asian countries and India, the largest producers and exporters of tamarind, who continue to grow sour types. Some farmers in Tamil Nadu grow selected superior cultivars which are known to be heavy bearers but the availability of grafted plants is limited to only a few cultivars and in a few locations. Only three improved cultivars are available in India, all of which are the sour types, although a number of selected lines are under development.

Continued attention to the genetic improvement of planting materials is essential for further commercial exploitation. Recent research on *Rhizobia*, mycorrhizae and the early growth of trees can be applied to the establishment of medium-scale plantations provided that suitable planting materials are produced through vegetative propagation and that such materials are readily available. A large number of constraints are apparent in achieving these goals, but the technology exists to overcome them as outlined in this monograph.

Where no priority research agenda exists at the different national levels, the value of international organisations becoming involved with efforts to improve tamarind and to develop sustainable cultivars and use is all the more apparent. International organisations can stimulate the exchange of germplasm, promote the development of planting supply systems and support research and development by making technologies widely available. The approach taken by ICRAF in Africa to collect, characterise and make available germplasm of tamarind, particularly for use in agroforestry systems, has made a positive impact in a very short time in a number of countries. ICUC continues to be a vehicle promoting better utilisation of neglected species such as tamarind and, as this monograph shows, is able to put researchers in one country in touch with others with similar interests elsewhere.

It will also be very clear from this monograph that much produce can be wasted due to the lack of organisation at the village level for harvesting, transporting produce and marketing. Very few data are available on marketing. Nonetheless training in aspects of production and marketing pioneered by Kasetsart University in Thailand in relation to small orchard production of sweet tamarind led rapidly to smallholders becoming involved in business planning. Such efforts need to be replicated so that ultimately fair price schemes will come into being and the value of cultivation will be realised.

Such concerted development at the local level will only be successful when backed by continued provision of improved planting materials and attention to quality aspects of products including product development, diversification and marketing.

The current situation therefore shows great promise for wider and better use of tamarind in a variety of situations: agroforestry, including much more testing of suitable intercrops in the early years of tamarind growth; in village co-operatives; and in small and medium sized plantations as a commercial crop.

Even though there are some limitations, tamarind could be better used in intercropping by improving tree architecture or changing spatial arrangements, as it will fit into various niches on small farms. Presently, sweet tamarind plantations are intercropped with annual crops in Thailand. Although desirable ideotypes have been proposed these are at a preliminary stage of development. When such ideotypes are developed they could have a direct impact on tropical agroforestry systems.

Another important aspect of tamarind is its food and medicinal value, which could safeguard food and nutrition security, alleviate poverty and improve health and the standard of living of rural populations. Tamarind is available when other food supplies are low, thus contributing significantly to the nutrition of low-income rural households. Certain communities which consume cassava, yams or plantains as their chief source of carbohydrate, need more protein in their diet. Tamarind seed protein contains highly favourable amino acids and could complement methionine + cystine levels in the diet, to alleviate protein malnutrition which is widely prevalent in developing nations.

Although medicinal values are claimed for various preparations made from tamarind leaves, pulp, flowers or both, only the antiascorbic and antioxidant properties of the pulp, laxative action of the fruit juice, and diuretic properties of the leaf sap are well established.

11.2 Research and technology needs

11.2.1 Understanding the genetic variation

Very little is known about the genetic variation of tamarind. Due to its outbreeding nature and exceedingly wide distribution in the wild or naturalised state no concerted effort has been made to strategically sample populations and analyse patterns of variation. This could be done by taking an eco-geographic approach. Because of the long-lived nature of the trees molecular and biochemical techniques of analysis should be combined with biometrical measurements and other assessments of traits of value in characterising any stocks to be put into working collections for potential use in genetic improvement.

Additionally research is needed on the effective size of breeding populations.

11.2.2 Genetic improvement

The genetic improvement goals are straightforward based on the available material. They are: faster growth and higher yielding lines for selection for different uses.

Since normal crossing is not an option, more trait specific work is needed so that provenance trials can lead to selections which combine the desirable characters, and then to cultivars developed from them. These should be developed to fit the different land-use systems of agroforestry, orchards/plantations, as well as certain stress conditions inherent in a number of wastelands which need to be rehabilitated.

11.2.3 Propagation and establishment

Once cultivars are selected, propagation methods are necessary to produce young plants and make them available to growers. Vegetative propagation techniques should be standardised, simple and easily performed by farmers.

Where official agencies are involved, attention should be paid to the protocols necessary for rapid propagation. Research is still needed here. Not enough is known about the needs for *Rhizobia* or mycorrhizal in tamarind cultivation. More research is needed. Whereas in commercial operations pellets can be used, smallholders will need to know whether they need to obtain soil from growing populations to mix into the mixtures they put into planting pits for optimum growth.

11.2.4 Management of plants

One area of research which needs much more emphasis is understanding flowering, fruit set and fruit production. The development of standardised relatively low-cost sprays to enhance fruit production is an urgent research need since growers will have to factor this cost into their cost-benefit analyses.

More attention needs to be paid to harvesting, currently a laborious and time-consuming operation. Rather than harvesting from a diverse age and size range of trees, the future is likely to relate to efficient harvesting techniques applicable to small-scale plantations.

11.2.5 Post harvest

Shelling by hand is common practice in many countries. It requires eight man-hours to shell 45 kg of fruits. Further work on the development of small-scale shellers would be required to improve the efficiency of processing.

Most of the rural and tribal peoples in different countries use tamarind products collected from nearby forests and non-forest areas. Processing technology at the producer level is lacking and heavy losses are reported. Simple methods for processing, storage and value addition should be developed. Although a number of processing technologies are available these are not widely disseminated among growers. This emphasises the need for extension programmes.

The brown-red colour of the pulp starts to deteriorate in storage and becomes black within a year. Improved methods for processing and storage need to be developed and standardised. Destruction of the pulp by insects and fungi during storage is also a problem and this needs attention by food technologists. There is a need to develop technologies for manufacturing tamarind products to make better use of the pulp and seeds which are produced in large quantities in most tamarind-growing countries. Value addition through product diversification is another area that deserves research attention.

11.2.6 Good economics and marketing

Whereas some data exist on marketing, most marketing systems are traditional and at the farm-gate. Prices received by growers and collectors are low. It will be essential to organise marketing channels, such as village level co-operatives, fair price shops or similar marketing institutions, so that the primary producers are not forced to dispose of their produce at lower prices. Local market surveys will be useful to identify potential markets for various products of tamarind. However, there is a total lack of socio-economic research at all levels along the production to consumption chain where women, men and children are all involved. Benefits can be quantified as on-farm and off-farm incomes and these measured in purchasing powers, credit, education opportunities etc. Whilst tamarind remains underutilised benefits from it can be lumped with other minor forest products but this is inappropriate if tamarind production is to be vigorously promoted.

11.2.7 International trade

It is noted that international trade, albeit small, is well established. This would be strengthened by the adoption of quality control standards but this requires research and policy changes by authorities.

11.2.8 Genetic conservation

Tamarind is so widespread that little attention has been paid to genetic conservation. Any needs for this will become much more apparent as soon as enhanced research on patterns of variation (see 11.2.1) is carried out. Existing *ex situ* collections are in no way conservation collections since they relate to working collections for selection or adaptation for tests of introduced materials. As genetic improvement is enhanced the landmark genetic lines will need to be conserved and collections will need to be more comprehensive. The genetic improvement itself would benefit from the inclusion in those collections of more representative variability, probably based on identification of ecotypes or geographical variants.

For the rehabilitation of degraded vegetation there is a justification for *ex situ* storage of seeds of diverse populations so that they may be used in any rehabilitation attempts to put back adequate heterozygosity. It would be interesting to carry out research to see whether clonal materials grown on marginal areas could, through propagation of their seeds, provide adequate heterozygosity for rehabilitation of vegetation, in which case seed storage would be needed as a back-up to other genetic conservation techniques.

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International Centre for
Underutilised Crops
International Water
Management Institute
127 Sunil Mawatha, Pelawatte,
Battaramulla,
SRI LANKA

International Plant Genetic
Resources Institute
Via dei Tre Denari 472/a
00057 Maccarese (Fiumicino)
Rome
ITALY

International Centre for Research
in Agroforestry (ICRAF)
Tree Domestication Programme
Nairobi
KENYA

Southampton Centre for
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School of Civil Engineering and
the Environment
University of Southampton
Southampton SO17 1BJ
UK

National institutions and individuals

AFRICA

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Centre National des Semences Forestieres
Ouagadougou
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Ecole de Faune
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Garoua
CAMEROUN

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Pharmaceutical Science Laboratory
Cairo
EGYPT

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University of Ghana
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GHANA

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BP 10662 Niamey
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Dept. of Biochemical and Applied Molecular Biology
Toxicology Section
Vom
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Department of Wildlife and Fisheries Management
University of Ibadan
Ibadan
NIGERIA

Department of Botany
University of Benin
Benin City
NIGERIA

Department of Food Technology
Federal Polytechnic
PMB 1037, Idah
Kogi State
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Dept. of Botany
University of Benin
Benin City
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Dept. of Chemistry
Ahmadu Bello University
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Maiduguri
PMB 1069
NIGERIA

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BP 1716
Dakar
SENEGAL

Dr. T. Guissou
URA Foret
ISRA
BP 2312; Route Hann
Dakar
SENEGAL

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Univ. Cheikh Anta Diop
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SENEGAL

Dr. M. Sembene
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Lab Protect Stocks
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SENEGAL

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Mogadishu
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Department of Entomology
Guangdong
CHINA

COSTA RICA

Consejo Nacional de Production
Direccion Mercadeo Y
Agroindustria
Depto. Sistemas Infomacion de
Mercados
San Jose
COSTA RICA

Dr. R. Lopez
Lab. of Nematology
Escuela Fitotecnia; Facultad de
Agronomia
Universidad de Costa Rica
San Jose
COSTA RICA

CUBA

Dr A. Mercado Sierra
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Dr R. Rodriguez
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DOMINICAN REPUBLIC

Dominican Horticulture Research
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Calle 7, Edif. 4, Apt. 301 Ens.
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Technology
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Spices Board
Ministry of Commerce,
Government of India
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MALAYSIA

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MALAYSIA

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University Putra
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Selangor
MALAYSIA

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Inst. Ecol. Alimentos
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Los Banos College
Laguna
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Appendix II. Institutions with collections of tamarind germplasm

BURKINA FASO

Centre National de Semences Forestieres BP 2682, Ouagadougou 01, Burkina Faso.
Tel: (226) 300857/301233; Fax: (226) 301232

Details of holdings:
taxon sample - *Tamarindus indica*
sample type - Wild/weedy species
geographical origin - Unknown
number of accessions reported - 9
updated - 26-08-1993

HONDURAS

Dept. de Atlantida Honduras, Centro Universitario Regional del Litoral Atlantico (CURLA), UNAH, m 8, Carr. La Ceiba-Tela, A.P. 89, La Ceiba, Dept. de Atlantida, Honduras.
Tel: (504) 441-0537/441-0603/441-1833; Fax: (504) 441-1832;

Jardin Botanico Wilson Popenoe de Lancetilla, Apartado Postal 49 Tela, Altantida, Honduras.
Tel: (504) 4481740; Fax: (504) 4481740; Email: prodebol@hondutel.hn

Details of holdings:
taxon sample - *Tamarindus indica*
sample type - Unknown
geographical origin - Unknown
number of accessions reported - 1
updated - 19-06-1999

INDIA

National Bureau of Plant Genetic Resources (NBPGR)
Pusa Campus
New Delhi-12
India

PHILIPPINES

Institute of Plant Breeding, College of Agri., UPLB Box 110, UPLB 4031 College, Laguna, Philippines.
Tel: 63-49-536-2298; Fax: 63-49-536-3438; Email: *opd@ipb.uplb.edu.ph*

Details of holdings:
taxon sample - *Tamarindus indica*
sample type - Wild/weedy species
geographical origin - Unknown
number of accessions reported - 46
updated - 02-01-1992

UNITED STATES OF AMERICA

Subtropical Horticultural Research Unit, USDA, 13601 Old Cutler Road, Miami, FL 33158, United States of America.
Tel: (1-305) 2389321; Fax: (1-305) 2555036; Web site: http://www.ars-grin.gov/ars/SoAtlantic/Miami/homes

Details of holdings:
taxon sample - *Tamarindus indica*
sample type - Unknown
geographical origin - Unknown
number of accessions reported - 15
updated - 29-08-1990

Source: International Plant Genetic Resources Institute (1998).

Appendix III. Seed suppliers directory

AUSTRALIA

Elison Horticultural Pty. Ltd.
PO Box 365, Nowra, NSW 2541, Australia
Tel: (61 44) 214255
Fax: (61 44) 230859

Harvest Seeds
325 Mc Carrs Creek Road
NSW 2084
Australia
Tel: (61 2) 94502699
Fax: (61 2) 94502750
E.mail: *harvest@0zemail.com.au*

M.L. Farrar Pty Limited
PO Box 1046, Bomaderry
NSW 2541
Australia
Tel: (61 44) 217966
Fax: (61 44) 210051

FRANCE

CIRAD-Foret
Laboratoire de Graines, Campus International de Baillarguet, BP 5035, 34032 Montpellier Cedex 01, France
Tel: (33 4) 67593751
Fax: (33 4) 67593733
E.mail: *labograine@cirad.fr*

HONDURAS

Tropical Seeds, S. de R.L
3Ave 5 Caile S.O., PO Box 116, Colonia Los Angeles, Siguatepeque, Honduras
Tel: (504) 732767
Fax: (504) 732767

INDIA

Bisht Enterprises
Baniyawala, Prem Nagar, Dehra Dun 248007 (U.P.), India
Tel: (91 135) 683191/683014
Fax: (91 135) 683331

Kumar International
Ajitmal 206121, Etwah (UP), India

Neelkantheshwar Agro-Seeds and Plantations
"B' Block Commercial Complex - B6/G4, Dilshad Garden, Delhi-110095, India
Tel: (91 11) 2274277, 2298494, 2299449
Fax: (91 11) 2112974

Shivalik Seeds Corporation
47 Panditwari, PO Premnagar, Dehra Dun 248007 (U.P.), India
Tel: (91 135) 683348
Fax: (91 135) 683776

Tosha Trading Company
161, Indra Nagar Colony, PO-New Forest, Dehra Dun, UP 248006, India
Tel: (91 135) 620984
Fax: (91 135) 620196

Tropical Forest Research Institute
PO RFRC, Mandla Road, Jabalpur 482021, Madhya Pradesh, India
Tel: (911 761) 322585, 84744, 84752; Fax: (911 761) 321759;
E.mail: *TFRI-DIR@x400nicgw.nic.in*

Viyai Seed Stores
PO Ranjhawawala (Raipur),
Dehra Dun 248008 (U.P.), India
Fax: (91 135) 629944

KENYA

Kenya Forestry Seed Centre
PO Box 20412, Nairobi, Kenya
Tel: (254 154) 32484, 32893;
Fax: (254 154) 32844

MALAWI

Forestry Research Institute of Malawi
PO Box 270, Zomba, Malawi
Tel: (265) 522866/522548
Fax: (265) 732784

NIGER

Centre des Semences Forestieres
BP 578, Niamy, Niger
Tel: (227) 723182/733339
Fax: (227) 732784

SINGAPORE

The Inland & Foreign Trading Co (Pte) Ltd.
Block 79A Indus Road #04-418,
Singapore 169589, Singapore
Tel: (65) 2722711 (3 lines)
Fax: (65) 27161118
E.mail: *iftco@pacific.net.sg*

TANZANIA

National Tree Seed Programme
PO Box 373, Morogoro,
Tanzania
Tel: (255 56) 3192/3903
Fax: (255 56) 3275
E.Mail: *ntso@twiga.com*

UGANDA

Forestry Research Institute (FORI)
PO Box 1752, Kampala, Uganda
Tel: (256 41)255163/5/244140, 251916/9
Fax:(257 41)234252/255165

Source: Salim *et al,* 1998.

Glossary

acuminate -	the shape of a tip or base of a leaf or perianth segment where the part tapers gradually and often in a concave manner.
adnate -	joined to or attached to: applied to unlike organs, e.g. stamens adnate to perianth.
albumen -	Starchy and other nutritive material in a seed, stored as endosperm inside the embryo sac, or as perisperm in the surrounding nucellar cells; any deposit of nutritive material accompanying the embryo.
androecium -	all the male reproductive organs of a flower; the stamens. cf. gynoecium.
angiosperm -	a plant producing seed enclosed in an ovary. A flowering plant.
annual -	a plant that completes its life cycle from germination to death within one year.
anterior -	front; on the front side; away from the axis.
anther -	the pollen-bearing (terminal) part of the male organs (stamen), borne at the top of a stalk (filament).
anthesis -	flowering; strictly, the time of expansion of a flower when pollination takes place, but often used to designate the flowering period; the act of flowering.
apex -	the tip of an organ, the growing point.
apical -	pertaining to the apex.
aril (arillus) -	a fleshy or sometimes hairy appendage or outer covering of a seed, growing out from the hilium or funiculus.
arillate -	provided with an aril.
auricle	(adj. auriculate) - small ear-like projections at the base of a leaf or leaf-blade or bract.
axil -	the upper angle formed by the union of a leaf with the stem.
axillary -	pertaining to the organs in the axil, e.g. buds, flowers or inflorescence.
axis -	the main or central stem of a herbaceous plant or of an inflorescence.
basal -	borne on or near the base.
bifid -	forked; having a deep fissure near the centre.
bilabiate -	two-lipped.
bipinnate -	(of leaves) a pinnate leaf with primary leaflets themselves divided in a pinnate manner; cf pinnate.
biseriate -	in two rows.
bisexual -	having both sexes present and functional in the one flower.
blade -	the flattened part of a leaf; the lamina.

bract - a much-reduced leaf, particularly the small or scale-like leaves in a flower cluster or associated with the flowers; morphologically a foliar organ.
bracteole - a secondary bract; a bractlet.
caducous - falling off early, or prematurely, as the sepals in some plants.
calyx - the outer whorl of floral envelopes, composed of the sepals.
carpel - one of the flowers' female reproductive organs, comprising an ovary and a stigma, and containing one or more ovules.
clone - a group of plants that have arisen by vegetative reproduction from a single parent, and which therefore all have identical genetic material.
connate - united or joined; in particular, said of like or similar structures joined as one body or organ.
convex - arched outward.
cotyledon - seed leaf; the primary leaf or leaves in the embryo.
cross pollination -the transfer of pollen from the anther of the flower of one plant to the flowers of a different plant.
crustaceous - of hard and brittle texture.
deciduous - falling at the end of one season of growth or life, as the leaves of non-evergreen trees.
decoction - herbal preparation made by boiling a plant part in water.
dehiscence - the method or process of opening a seed pod or anther.
derived - originating from an earlier form or group.
dicotyledon - a flowering plant with two cotyledons.
emarginate - having a shallow notch at the extremity.
entomophilous - insect pollinated.
exalbuminous - without albumen
exocarp - the outer layer of the pericarp or fruit wall.
falcate - scythe-shaped; curved and flat, tapering gradually.
filament - thread; particularly the stalk of the stamen, terminated by the anther.
filiform - thread-shaped, long, slender and terete.
flexuose - zig-zig; bending from side to side; wavy.
genus - a group of closely related species, the taxonomic category ranking above a species and below a family.
glabrous - not hairy.
glaucous - bluish white; covered or whitened with a very fine, powdery substance.
gynoecium - all the female parts of a flower.
hypocotyl - the axis of an embryo below the cotyledons which on seed germination develops into the radicle.
indehiscent - not regularly opening, as a seed pod or anther.
indigenous - native and original to the region.

inflorescence - the flowering part of a plant and especially the mode of its arrangement.
lateral - side shoot, bud etc.
mesocarp - the fleshy middle portion of the wall of a succulent fruit between the skin and the stony layer.
monophyletic - descended from a single ancestral line, see also: polyphyletic.
mucronate - terminated abruptly by a distinct and obvious spur or spiny tip.
naturalised - to cause a plant to become established and grow undisturbed as if native.
nectar - sweet secretion of glands in many kinds of flower.
nectiferous - producing nectar.
nodose - knobbly, knotty.
oblique - slanting, unequal sided.
obovate - inverted ovate; egg-shaped, with the broadest part above.
orbicular - circular.
ovary inferior - with the flower-parts growing from above the ovary.
ovary superior - with the flower-parts growing from below the ovary.
ovate - egg-shaped, with the broader end at the base.
ovule - the body which after fertilisation becomes the seed.
panicle - a loose irregularly compound inflorescence with pedicellate flowers.
panicled - borne in a panicle.
paripinnate - a pinnate (compound) leaf with all leaflets in pairs.
pedicel - a tiny stalk; the support of a single flower.
pendulous - more or less hanging or declined.
perianth - the floral envelope consisting of the calyx and corolla.
perigynous - adnate to the perianth, and therefore around the ovary and not at its base.
petal - a division of the corolla; one of a circle of modified leaves immediately outside the reproductive organs, usually brightly coloured.
petiole - the stalk of a leaf that attaches it to the stem.
phenotype - the morphological, physiological, behavioural, and other outwardly recognisable adaptations of an organism that develop through the interaction of genes and environment.
pinnate - a compound leaf consisting of several leaflets arranged on each side of a common petiole.
polyphyletic - having members that originated independently, from more than one evolutionary line.
propagate - to produce new plants, either by vegetative means involving the rooting or grafting of pieces of a plant, or by sowing seeds.
protogynous - referring to a flower where the shedding of the pollen occurs after the stigma has ceased to be receptive.

pubescent - covered with hairs, especially short, soft and down-like.
pulvinus - a swelling at the base of a leaf or leaflet.
raceme - a simple inflorescence of pediceled flowers upon a common more or less elongated axis.
rachis - the main stalk of a flower cluster or the main leafstalk of a compound leaf.
radicle - the portion of the embryo below the cotyledons that will form the roots.
reticulate - in the form of a network, netveined.
retuse - with a shallow notch at a rounded apex.
scarify - to scar or nick the seed coat to enhance germination.
scurfy - covered with tiny, broad scales.
self pollination - the transfer of pollen from the anther of a flower to the stigma of the same flower, or different flowers on the same plant.
sepal - a division of a calyx; one of the outermost circle of modified leaves surrounding the reproductive organs.
sessile - without a stalk.
sheath - a tubular envelop.
stamen - one of the male pollen-bearing organs of the flower.
staminode - a sterile stamen, or any structure without an anther corresponding to a stamen.
stigma - that part of a pistil through which fertilisation by the pollen is effected.
stipule - an appendage at the base of a petiole, often appearing in pairs, one on each side, as in roses.
style - the usually attenuated portion of the pistil connecting the stigma and ovary.
symbiotic - the living together of different species of organism which may or may not be to their mutual benefit.
testa - the outer seed coat.
tomentose - covered with a thick felt of radicles; densely pubescent with matted wool.
transverse - cross-wise in position.
tropism - the movement of an organism in response to an external source of stimulus, usually toward or away from it.
zygomorphic - capable of division by only one plane of symmetry.

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