Towards Sustainable Abundance: The Advancements in Tamarind Production Technology

Abstract:

Tamarind, a tropical fruit-bearing tree, is essential for food, pharmaceutical, and industrial applications. Advancements in tamarind production technology are needed to ensure sustainable cultivation and efficient processing. This review focuses on innovative cultivation practices, breeding strategies, pest management, post-harvest practices, and value addition. It explores intercropping, agroforestry, and water-efficient irrigation systems to maximize land utilization and water resources. Integrated pest management strategies, such as biological control and organic pesticides, are proposed to reduce chemical dependency, minimize environmental impact, and maintain ecological balance. Post-harvest technology, including innovative harvesting, cleaning, storage, and processing techniques, is evaluated to maintain product quality and shelf life. The review also examines the economic viability and value addition opportunities within the tamarind industry, identifying potential product diversification and reducing the carbon footprint.

Keyword: Imli; Tamarind cultivation; Tamarindus indica; Sustainable practices; Tamarind processing

Introduction

Tamarind (*Tamarindus indica* L.) is a monotypic genus belonging to the subfamily Caesalpinioideae of the family Leguminosae (Fabaceae) with a somatic chromosome number of 2n = 24 (Rajamanickam C *et al*., 2023). The fruit of the tamarind tree, or "Assam tree," is known as "imli" or "Indian date." This multipurpose tree can grow in any type of soil and is frost- and drought-tolerant (Rajamanickam, 2020). Mostly utilized for its fruits, which are either consumed raw or processed, used as a spice or condiment, or the fruits and seeds are processed for various uses (Shah, 2014). India produces roughly 2.5 lakh metric tonnes of tamarind pulp each year, and there is potential for exporting juice concentrates and pulp powder to European nations. When properly dried with salt, tamarind pulp has a great ability to preserve food (Venkataravana *et al*., 2020). Since the tamarind has so many beneficial qualities, both rural and urban residents use almost every component of the tree (Singh *et al*., 2021).

Origin, History and Distribution

Tamarindus indica L. is a tropical plant native to tropical Eastern Africa (Sookying *et al*., 2022). Ethiopian traders introduced it to India centuries ago (Chimsah *et al*., 2020). Tamarind, originating from Persian and Arab sources, reached India and was called 'Tamar-i-hind', the Persian word means 'Date of India' Its Sanskrit name 'Amlika' indicates its ancient presence, with mention in Indian Brahmasamhita scriptures from 1200 to 200 BC (Rao and Mathew, 2012).It is mentioned in Ayurvedic literature as "amla" (Caraka Samhita, and Sushruta Samhita) (Joshi *et al*., 2023).The fruit has medicinal properties and culinary applications, with starch-rich seeds used in textile industries and consumption. Tamarind is said to be pan tropical (Chimsah *et al*., 2020). Widespread in tropics and subtropics, cultivated in 54 countries, particularly in African, Asian, and South American regions (Singh *et al*., 2021;Sudha *et al*., 2022).Cultivating in various states of India, including Madhya Pradesh, Bihar, Andhra Pradesh, Karnataka, Tamil Nadu, West Bengal, Orissa, Kerala (Idris *et al*., 2018).

Taxonomy

Tamarind belongs to the 3rd largest family of angiosperms, Fabaceae with 700 genera and nearly 17000 species (Singh *et al*., 2021).It is a member of monotypic genus *Tamarindus* and comprises one species, *indica*.

Kingdom	:	Plantae
Subkingdom	:	Tracheobionta
Superdivision	:	Spermatophyta
Division	:	Magnoliophyta
Class	:	Magnoliopsida
Subclass	:	Rosidae
Superorder	:	Rosanae
Order	:	Fabales
Family	:	Fabaceae
Subfamily	:	Caesalpinoideae
Tribe	:	Detarieeae
Genus	:	Tamarindus
Species	:	*Tamarindus indica*

(Joshi *et al*., 2023).

Botanical Description

Tamarind is an evergreen tree with a 30m tall, 8m diameter trunk, light grey to brown color and short fissured, scaly trunk (Singh A.K. *et al*., 2021;Singh *et al*., 2021).Its crown is dense and spans up to a circumference of 12 m in diameter (Srinivasarao and Kumar, 2015).The plant has wide, crooked, and droopy branches with red exudate when damaged. Its roots are deep, with tap root and lateral root systems. Leaves are paripinnate, distributed alternately, and have a short petiole. The leaves fold in absence of light due to lupeol degradation. The inflorescence is a terminal raceme with up to 18 flowers, with flower buds developing within 20 days. The flower development takes 18 to 26 days, with pedicellate and bracteate flowers. The flowers are bisexual, protogynous, nectariferous, and entomophilous, leading to cross pollination. Anthesis occurs at 6 AM, with a cream, pale yellow, pink, or white turbinate calyx and a cream, pale yellow, pink, or white corolla. The androecium consists of three fertile stamens, with anthers that dehisce longitudinally after opening the flowers.The gynoecium is superior, with an adnate ovary and up to 18 ovules.

The style is green, long, and hooked with a subcapitate stigma. Stigma is most receptive on the day of flower opening. Flowers are irregular in length and diameter.

The pods, oblong, curved, or straight fruits, are 5-10 cm long and 2 cm wide. When Raw, they are brittle and light grey to brown. When ripe, the pulp softens and the seeds are hard, red to purple-brown, orbicular to rhomboid, flat, glossy, and have a central depression. Pods take 10 months to ripen and are indehiscent (Choudhary and Dongre, 2022).

Properties of Tamarind

A typical fruit or pod has 55% pulp, 34% seeds, and 11% shell and fibers (Muzaffar, 2017). The testa, or seed coat, makes up 20–30% of the seed, and the endosperm, or kernel, makes up 70–75% (Shankaracharya, 1998). The pods, which have a variety of uses and may be used either processed or raw. The other fruit parts, which are also eaten, contain minerals and nutrients (Okello *et al*., 2017). Pulp contains high sugar content (30-40%), making it suitable for commercial applications like concentrates, pickles, confections, and powders (Abdel Moneim E. Sulieman *et al*., 2015).

Physical description

Tamarind had tall pods, brown shell, red flesh, and six seeds in its fruit. The fruits had a transverse diameter between 2.50 and 3.00 cm and a longitudinal diameter between 1.30 and 1.70 cm. The length ranged from 3.70 to 11.10 cm (Hamacek *et al*., 2013).

Chemical Composition

Tamarind pulp is rich in minerals, protein, and carbs but lacks water. It contains 20.6 percent water, 3.1% protein, 0.4 percent fat, 70.8 percent carbohydrates, 3.0% fiber, and 2.1% ash. The fruit's exact composition varies depending on its cultivation (Emmy De Caluwé, 2010).

Physicochemical characterization

Tartaric acid, a rare biological source, is the primary acid in tamarind pulp. Its [SS/TA] ratio measures tamarind maturity and flavor, indicating the equilibrium between sugars and organic acids. In comparison to other fruits, Tamarind contains higher levels of vitamin C (4.79 mg/100 g) and folates (59.35 g/100 g) compared to other fruits, but only 108.78 g of vitamin E per 100 grams (Ashvini V Joshi *et al*., 2023).

Antioxidant Properties of Tamarindus indica

Polyphenols are the primary class of natural antioxidants found in plants, found in various parts like bark, fruits, leaves, nuts, roots, and seeds (Devi and Boruah, 2020). Flavonoids, a subclass of polyphenols, are the second-largest family. Tamarindus indica, a plant with remarkable antioxidant properties, is a notable example (Lu *et al*., 2011).

Table 1: Nutracueticals of tamarind

Source	(Singh, Naruka, *et al*., 2021)	(Ishaku *et al*., 2016)	(Martin, 2007)	(El-Siddig *et al* , 2006)
Nutrient	**Food value**			
Water	17.8–35.8g	-	-	35.29 g per 100 g
Thiamin	0.33 mg	-	-	-
Protein	2-3g	9.15%	2.00-9.10%	-
Riboflavin	0.1 mg	-	-	-
Fat	0.6g	6.24%	0.50-3.10%	-
Niacin	1.0 mg	-	-	-
Carbohydrates	41.1–61.4g	60.02%	56.70-82.60	50.07 g per 100 g)
Phosphorus	34-78 mg	-	-	-
Iron	0.2-0.9 mg	-		-
Pectin (calcium	2.4 %	-	2.00-4.00	-

pectate)				
Vitamin C	44 mg	-	-	-
Fiber	2.9g	7.16%	2.20-18.30	4.13 g per 100 g
Ash	2.6-3.9g	6.24%	2.10-3.30	-
Tartaric acid (free)	9.8 %	-	8.40-12.40	-
TSS	54-69.9 %	-	-	-
Calcium	34-94 mg	-	-	-
Tartaric acid(combined)	6.7 %	-	8.00-18.00	-
Invert sugar	38.2 %	-	25.00-45.00	-
Moisture	-	11.19%	15.00-30.00%	-
Starch	-	-	5.70	-
Tannin, (mg)	-	-	600.00	-
Ascorbic acid, (mg)	-	-	3.00-9.00	-
E-carotene equivalent (Pg)	-	-	10.00-60.00	-
Thiamine (mg)	-	-	0.18-0.22	-
Riboflavin (mg)	-	-	0.07-0.09	-
Niacin (mg)	-	-	0.60	-

Table 2: Some chemical composition of tamarind pulp	
Parts	**Chemical constituents** (Hamacek *et al*., 2013)
Leaves.	Pulps contain invert sugar, citric acid, pipecolic acid, nicotinic acid, 1-malic acid, volatile oils, vitamins B3, C, vitexin, isovitexin, benzyl benzoate, cinnamates, serine, pectin, beta alanine, proline, phenylalanine, leucine, potassium, 1-malic acid, tannin, and glycosides.

Fruits.	Fruits contain Furan derivatives and carboxylic acid. Phlorotannins, apple acid, grape acid, succinic acid, citric acid, tartaric acid, pectin, invert sugar.
Seeds.	Seed extract contains campesterol, β-amyrin, β-sitosterol, palmitic acid, oleic acid, linoleic acid, and eicosanoic acid. Mucilage, arabinose, xylose, galactose pectin, glucose, and uranic acid were also found. A new bufadienolide and cardioid were identified. Cellulose, albuminoid, amyloids, phytohemagglutinins, and chitinase were also found.
Stem bark.	Tannins, saponins, glycosides, peroxidase and lipids
Root bark	N-hexacosane, eicosanoic acid, β-sinosterol, (+)-pinitol, octacosanyl ferulate, 21-oxobehenic acid.

Table 3: Physico-chemical properties of tamarind

Physico-chemical properties	**Pulp**	**Seed**	**References**
Saponification value (mg KOH g-1)	301.3	266.6	(El-Siddig *et al*, 2006)
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	

Table 4: Mineral composition of tamarind

Mineral Composition of fruit Pulp Mineral mg/100g	**Pulp**	**Pulp** (Ishaku *et al.*, 2016)	**Seed**	**Seed** (Yusuf *et al.*, 2007)	**Kernel**	**Testa**
Calcium	81.0-	21.57	9.3-786.0	10.0	120.0	100.0

	466.0					
Phosphorus	86.0-190.0	17.10-18.40 (El-Siddig and Williams, 2006)	68.4-165.0	25.5		
Magnesium	25.0-72.0	10.54	17.5-118.3	15.0	180.0	120.0
Potassium	62.0-570.0	187.73	272.8-610.0	21.0	1020.0	240.0
Sodium	3.0-76.7	112.76	19.2-28.8	2.1	210.0	240.0
Copper	0.8-1.2		1.6-19.0			
Iron	1.3-10.9	1.05	6.5	75.9	80.0	80.0
Zinc	0.8-1.1		2.8		100.0	120.0
Nickel	0.5					
manganese		0.13	0.9			

Source: (Parvez *et al*., 2003).

Table 5: Uses of Tamarind	
Food	Fruit pulp is used as a preservative and in various culinary dishes like chutney, tamarind juice concentrate, pulp powder, jams, syrups, candy, and souring porridge. It is also consumed raw as a snack.
Fodder	Animal feed made up of fried seeds and foliage
Agriculture	Flowers are used to make honey, and their roots fix nitrogen in the soil.
Fuel	Tamarind wood is potential for charcoal and firewood, but not widely used in Southeast Asia.
Timber	The sapwood is light yellow and the heartwood is dark purplish brown, marketed in the USA as "madeira mahogany," is used for various tools, furniture, utensils, poles, posts, boats, and construction materials.
Tannins	Tannins found in both leaves and bark can be used to make ink and dye.
Lipids	Seed oil is used in paints, varnishes, and oil lamps.
Medicine	Bark decoction, leaf decoction, pulp, and seeds are all plant parts with medicinal value for treating sores, ulcers, throat infections, rheumatism, cough, fever,

	intestinal worms, conjunctivitis, scurvy, dysentery, and diarrhea.
Other uses	Wood is pulverized for mulch, cleaned for utensils, and used for fabric size. Trees serve as windbreaks, living fences, and attractive plants in parks, roadways, and riverbanks.

Source: (Kumar *et al*., 2020; Narina and Catanzaro, 2018; Raja *et al*., 2022).

Genetic Resources

All Tamarind plantations in India have originated from seedlings and are heterogenous having diverse characteristics. Seedling plants exhibit heterozygosity in morphology, physiology and phenology (Pareek and Awasthi, 2002). This extends the range of desirable traits for crop improvement. Brown pulped and Red pulped types were reported (Hernandez-Unzon and Lakshminarayana, 1982). Tamarind plantations in Maharashtra and Madhya Pradesh showed wide variations in sweetness, acidity, size, shape and bearing habits (Karale *et al*., 1999; Keskar *et al*., 1989; N.Shinde; and L. V. Kulval, 1995).

Table 6: Tamarind plantations in four states

Tamil Nadu	**Maharashtra**	**Karnataka**	**Andhra Pradesh**
85 clones evaluated at Periyakulam Horticultural College (Azhakiamanavalan and Vadivel, 1997). Institute of Forest Genetics and Tree Breeding identified 12 phenotypes in 1994 at	120 accessions evaluated at Pune College of Agriculture (Sharma and Bhardwaj, 1997). 87 genotypes were identified and categorized as sour, sweet and red type (A.R.Karale, 2000) Fruit Research Station, Aurangabad has 350 trees under germplasm evaluation maintained under Marathwada Agricultural University, Parbhani	Forest department of Karnataka and University of Agricultural Sciences, Bangalore. collaborate to evaluate 230 plus trees and 40 plus tree	Department of Forest records 52 tree genotypes from tamarind tree surveys in Chittoor and Anantapur districts. Tamarind genotypes were classified into five groups based on fruit characteristics: long, bold, medium, small,

Kanyakumari (Bennet *et al*., 1997).	Out of 195 plus elite trees, 5 elite types (T-9, T-10, T-11, T-12 and T-13) were identified at Ahamadnagar and Satara districts (Keskar *et al*., 1989).	lines. (Murthy, 1997)	curved, irregular, and sweet (P.N.Ravindran *et al*., 2006).

SWEET TAMARIND

Pithecellobium dulce (Roxb.) Benth. Various nutrients and antioxidants are abundant in delicious tamarind fruits. Root and bark decoctions are taken orally for diarrhea, heamoptysis, chest congestion, and internal ulcers. Seed juice is inhaled for chest congestion, and pulverized seeds are ingested for internal ulcers. Leaves can be applied as a plaster, and when taken with salt, can cure indigestion but also produce abortion. Root bark may also be used for dysentery and as a ferbrifuge (Meena *et al*., 2022).

Crop Improvement

Significant crop improvement can be done by selecting plus trees and maintaining by multiplication through clonal propagation.

Varieties

The regional varieties fall into two categories: "Brown sour types" and "Reddish sweet types."

Local selections are: Cumbum selection from Madurai district; Rahuri selection from Maharashtra; Karur urigam tamarind from Karur; Kangadevanapalli tamarind and Dever Ullimangalam tamarind (P.N.Ravindran *et al*., 2006). Bangalore Tamarind, Tumkur Tamarind, Hosur Tamarind, Krishnagiri Tamarind, Natham Tamarind, Nagarkoil Tamarind, Villupuram Tamarind, Ranchi Tamarind, are some of the most well-known local varieties (Farooqi *et al*., 2005).

Below is a list of some tamarind improvements.

1. **Periyakulam-1 (PKM-1)**: It was released in 1992 by Horticultural College and Research Institute, Periyakulam. It is a clonal selection from germplasm. It is an early bearer. Its high pulp recovery is 39%. The interior side of the pulp exhibits the distinctive white colour will be, signifying its exceptional quality. This choice offers significant levels of ascorbic acid (3.95 mg/100 g) and tartaric acid (17.1%). It has a high yield of 263 kg/ha, Typically, seeds and grafts are used for propagation (Suresh *et al*., 1992;Tania *et al*.,

2018) findings showed that variety PKM-1 was superior in terms of plant height (445.33–569 cm), TSS (480 Brix), total sugar (40.33–40.33 g), and lower acidity (6.7 mg) in West Bengal.

2. **Urigam:** In Tamil Nadu's Dharmapuri district, it is a superior local genotype that may be found near Urigam, a small village near Thenkanikottai. The tree is little and has branches that resemble those on umbrella. The pods are long, fleshy, and tasteful. The pods have a typical inward curve and are flat. Each fruit weighs between 150 and 200 grams. The range of seeds is 10 to 12. Flowers start to bloom slightly later than usual, in March, and fruits are ready to be picked in July. In a trial by (Tania *et al*., 2018) the variety Urigam performed better than other varieties in West Bengal (Geetha, 1995).
3. **Prathisthan and HO 263**: These cultivars were released for commercial growth in the area by Fruit Research Station, Himal Bagh, Aurangabad, Maharashtra (P.N.Ravindran *et al*., 2006).
4. **NTI-19 (DST-1)**: This variety produces well in the Karnataka district of Dharwad. The pods are large in size. In 4-5 years after planting, the grafted plants begin to produce enormous pods. The fifth year, each plant produces an average of roughly 3 kg.
5. **Red tamarind:** The Tamil Nadu Agricultural University advises cultivating this type. The pulp, which is red in colour and in high demand in Arabian nations.
6. **GKVK-6 and GKVK-33:** These two are local varieties made released by the Gandhi Krishi Vignana Kendra, Bangalore's UAS Division of Horticulture (Farooqi; *et al*., 2005).
7. **GKVK 17:** When compared to GKVK-6, this cultivar exhibits a regular fruit-bearing habit and a tree canopy resembling an umbrella with average yield of 100.81 kg/tree. It has been recommended for the Southern regions of Karnataka (Venkataravana *et al*., 2020).
8. **Yogeswari,** an attractive red pulp variety that has been regarded as a special variety, is gaining in popularity (P.N.Ravindran *et al*., 2006).

Soil

Tamarind tree thrives in various soil types, including poor, rocky terrain, ravines, and degraded terrain in India. It tolerates sodic and salty soils and requires minimal cultivation (Ndiate *et al.*, 2022). Tamarind growth thrives in loamy, deep, well-drained alluvial soil, promoting long tap roots, while red sandy loam soils in Andhra Pradesh, India, are suitable (Rao *et al*., 2000).siltclay and clay soils were not suitable (Kelly and Cuny, 2000). The tree cannot stand waterlogging it thrive next to termite or ant mounds. The ideal pH for tamarind being 5.5–6.8, which is slightly acidic (El-Siddig *et al.*, 2006).

Climate

Tamarind has a wide geographic distribution in the sub- and semi-arid tropics. Tamarind thrives on evenly distributed 500- 1500mm annual rainfall (Fandohan *et al.*, 2015). Effect of climatic conditions on flowering and fruiting of *Tamarindus indica* (Fabaceae). Tamarind can withstand up to 4000 mm of annual rainfall.it is a tropical climate tree, can tolerate temperatures as low as 9.5 °C and as high as 33 °C annually. Young tamarind trees are vulnerable to fire, frost, and strong winds. With thick branches and a deep root system, they are nicknamed "hurricane-resistant" due to their ability to withstand powerful typhoons and cyclones (Rachie,1979). grows at 0-2000 m, but absence at higher elevations is more due to temperature drop than elevation (Azad, 2018).

Propagation

Seed dissemination is the most common method, but it doesn't breed true to type due to heterozygosity and prolonged juvenile periods in plants (Karale *et al.*, 1997). In recent years, methods for vegetative propagation have been developed.

Seed propagation

Harvest fresh, mature fruits by examining a brittle epicarp, and cut or shake pods if nearby (Morton, 1987).

Ripe pods are harvested in March and April, dried in the sun, and seeds removed. They are separated from the edible pulp by hand kneading and washing. Clean seeds are dried in the shade and stored in gunny bags. Seeds have a shelf life of six months, and optimal harvesting occurs at peak maturity. An established tree can yield three quintals of fruit annually, containing around 80 kg of seeds. Direct sowing requires 20 kg of seeds per hectare of land (P.N.Ravindran *et al.*, 2006). Monkeys are the primary seed disperser in South India. Tamarind seeds germinate 13 days, potentially up to a month (Jøker, 2000). To achieve optimal germination, wait 45 days after planting. Hastened germination can be achieved by removing hard seededness with acid or mechanical scarification and soaking in hot water (El-Siddig *et al.*, 2006).

Soaking seeds in hot water breaks dormancy, promoting germination. Exposed batches to 50% sulphuric acid for 60 minutes had the highest germination rate (Muhammad and Amusa, 2003;MacDonald *et al*., 2002). Tamarind seeds germination increased with methanol pretreatment, while upright planting with micropylar end facing upwards increased vigor and germination (Parameswari *et al*., 2001).

Nursery beds sown seeds in March and April, and within a year, seedlings reach a height of at least 80 cm. In India, seedlings are typically planted between 0.4 and 2 meters tall. In Tamil Nadu, transplants are better after two years. Overgrown seedlings can be successfully transplanted as stumped seedlings with stem and tap root lengths cut to 5 cm and 20-25 cm, respectively (Martin, 2007).

Vegetative propagation

Vegetative propagation procedures for large-scale multiplication and genotype characteristics include root and stem cuttings, air and stem-layering, budding, and grafting for tamarind (El-Siddig *et al*., 2006;Yahia and Salih, 2011). Stem cuttings are an affordable and simple method for propagating tamarind, with a 39.9% success rate in October, followed by November and June (P.N.Ravindran *et al*., 2006). Grafts gain popularity due to compact growth and early yields, bearing fruit in the third or fourth year after planting (Pruthi, 2001). Vegetative reproduction techniques like shield and patch budding, cleft grafting, whip grafting, and approach grafting are effective but costly and time-consuming. Veneer and soft wood grafting have shown potential for propagating tamarind, with graft success rates of 49% and 68%, respectively. Wood grafting was successfully used to increase tamarind yield in March and April on 8-month-old seedlings with 22-32 cm height and 0.3-0.4 cm diameter (V.Kulwall; *et al*., 1997). Research shows 74% success rate in approach grafting compared to 25% standard grafting (Pathak *et al*., 1991). Study suggests patch-budding for faster tamarind reproduction on large scale. Tamarind has been tested using air layering, with shoots rooted at 37% when 4000 ppm IBA was applied. Higher hormone concentrations led to higher rooting percentages (P.N.Ravindran *et al*., 2006).

Tissue culture

On MS medium containing BAP, found high frequency regeneration from excised cotyledon. On MS, rooting was accomplished using IAA Micro shoots from tamarind seedling explants produced several shoots and rooted (Mowobi *et al*., 2016). MS medium containing 0.5 mg/IBA, 0.5 mg/1 KN, and 0.1 mg/1 IAA was sufficient for generating 2-3 multiple shoots. On MS medium containing 0.2 mg/l of IAA, IBA, and NAA, Rhizogenesis was promoted (Olomola *et al*., 2019).

The study found that ideal in vitro culture conditions for high-frequency plant regeneration from Urigam seedling stem pieces were found to have the highest response to shoot bud differentiation, earliest reaction, and the greatest number of multiple shoots per culture. Axillary buds of Urigam induced numerous shoots (MGanga; and Balakrishnamoorthy, 1997).

Orchard establishment

Plant from July to November, with a distance of 5-13 meters between plants. For a pure stand plantation, the final spacing should be 13 x 13 meters square or on a triangle. For optimal spacing, use larger density plants and thinning twice to achieve 8-15 x 8-15 meters (El-Siddig *et al.*, 2006). Seedlings require 10mx10m or 13mx13m spacing, while grafts and buddings require 6mx6m spacing (Farooqi; *et al*., 2005). Tamarind is grown at 8 × 8 m, 8 x 12 m, or 12 x 12 m in some regions of India. For commercial planting, a spacing of 10 x 5 m has been advised, and 250 trees will be sufficient to cover one hectare (El-Siddig *et al.*, 2006). and 100 plants per acre are needed in 1 m3 trenches, filled with FYM, topsoil, and 10% dust. Plant seedlings or grafts in the center, keeping the graft-union above ground. Stack young seedlings to protect against wind (Pruthi, 2001).

Tissue culture-raised plants bloom at an average height of 3.7 meters, compared to seed-raised plants at 8 meters. To ensure optimal growth, it is recommended to plant more tissue culture-developed plants per unit area, with 156 plants per hectare at 9 m x 9 m spacing. Trees transplanted should be secured against animals and monkeys to prevent damage to seedlings and fruit consumption (Hocking, 1993).

Irrigation

Irrigation aids early growth establishment, particularly during dry seasons. (Yaacob and Subhadrabandhu, 1995). Rainwater harvesting promotes growth and fruiting in dry areas; irrigation benefits tamarind (de Lima Neto *et al*., 2018).

Manuring

Neem cake, groundnut cake, and superphosphate combined with liquid manuring stimulated seedling growth in six-month-old trees (Sambandamoorthy and Vadivel, 1996).

Organic manures like farm yard manure and neem cake increased crop yield during rainy days (Kumar *et al.*, 2020). A complete fertilizer mixture comprising 200 g of nitrogen, 150 g of phosphorus and 250 g of potassium along with 25 kg of farm yard manure applied annually to each tree is beneficial for a steady state of productivity (Mayavel *et al.*, 2018).

Use of biofertilizers

Tamarind seedlings respond positively to soil inoculation of up to thirteen VAM fungi, resulting in increased plant height, leaf number, stem girth, and biomass production. This response increases phosphorous and zinc levels, root colonization, and external hyphal networks. Tamarind responds positively to *Gigaspore margarita* and *Glomus fasciculatum,* and VAM inoculation significantly improves eight-month-old container-grown seedling growth. Rock phosphate is the best addition for optimal growth (Reena and Bagyaraj, 1990).

Pruning and training

Tamarind is a compact tree with symmetrical branches. Young trees require pruning to develop 3-5 well-spaced branches into the main scaffold structure. Regular pruning rejuvenates fruiting wood and regulates tree size in closely planted orchards (Parthasarathy; *et al*., 2008).

Weed management

In new and old orchard, hoeing, hand weeding and ploughing the land 2-3 times in a year is done to suppress weed growth. Intercropping and mulching is may be followed to control weeds (Singh, Mishra, *et al*., 2021).

Flowering, pollination and fruit set

Tamarind trees in South India bloom from April to July, with peak flowering occurring in May-June. New leaves appear in May, followed by flowers. Flower opening starts at 5:30 am, with peak anthesis at 6:30 am. Mature anthers are reddish brown and dehisce by longitudinal splitting of lobes. Pollen grains are round with an average diameter of 15 um, with a 96.5% fertile percentage. Stigma is receptive from one day before anthesis to two days after anthesis. Tamarind is predominantly cross-pollinated, with red ants playing a crucial role in pollination (Ravindran, 2006).

Tamarind fruit set is poor, causing large abscission of flowers and fruits. Factors contributing to poor fruit set include fertilization failure, sterility, defective pollen grains, slow growth, or early degeneration (Lokesh *et al*., 1997).

Tamarind flowers profusely, but fruit set is low under natural conditions (3-5%). Artificial cross pollination can increase it to 50-55%, due to pollen limitation and floral abnormalities (Karale *et al*., 1999).

Tamarind's fruit set increased in controlled cross-pollinated flowers, indicating partial self-incompatibility. High pollinators and visiting trees led to increased fruit set, indicating tamarind's self-incompatibility (Usha, 1987). 4-CPA, NAA, and GA were found to be more effective in increasing tamarind fruit set (Feungchan *et al*., 1996).

Floral biology

Inflorescence racemes are small, drooping racemes measuring 5-10 cm in length, with terminal and lateral drooping. The flowers are bisexual and 2 to 2.5 cm in diameter, with pedicels about 5 mm long. The bracts are fragrant and zygomorphic, nearly as long as the flower bud. There are two boat-shaped bractioles, 8 mm long, and four sepals, up to 1.5 cm long. The plant has five petals, with the posterior and lateral ones being large and showy, slightly exceeding the calyx. There are three fertile stamens, with filaments connate and alternate with bristle-like staminodes. Anthers are transverse, reddish brown, and dehisce longitudinally. The ovary is superior and unicarpellary, with up to 18 ovules and a green, hooked style (Purseglove, 1987).

Fruit Growth and Development

The fruit growth process involves three phases: prematuration (63%), lignifications and stone cell formation (67%), and ripening (17%). Prematuration involves maximum cellular activity, while lignifications and stone cell formation increase fruit weight and size. Ripening occurs 29 weeks after anthesis and lasts 17% of the growth period. During ripening, the peel separates from the pulp, moisture content decreases, total sugars increase, and acid content doubles. The growth curve is sigmoid after maturation, and the fruit takes 245 days from set to harvest (Hernandez-Unzon and Lakshminarayana, 1982).

Crop diversification

Intercropping and multistory cropping are practices that grow annuals or short-duration crops in interspaces during their formative years. Intercropping maximizes land and space use efficiency, generates additional income during the unproductive phase, and protects interspace from losses from weeds, erosion, radiation, temperature, wind, and water. These practices enrich interspace with nitrogen-fixing legume crops like peas, gram, lentil, black gram, cowpea, cluster beet, and okra (Singh, Mishra, *et al*., 2021).

Pest

Tamarind faces various pests, including shothole borers, toy beetles, caterpillars, bagworms, mealy bugs, and scale insects (Coronel, 1991). *Ramaswamiahiella subnudula* and *Halothrips ceylonicus* Schmutz are yellowish thrips that attack tamarind, Controlling them is possible using dimethioate spray at 20-30 ml/10 litres of water or Fenthion spray at 10-15 ml/10 litres of water (Gunasena, 1999).

Eublemma ungulifera Moore attacks flowers, weakening them and causing them to dry and fall from trees. Tamarind mealybug, *Drosichiella tamarindus (*Green), Tamarind weevil, *Sitophilus linearis* Tamarind fruit borer, *Phycita orthoclina* Meyrick (Joshi and David, 2018).

Cydia palamedes Meyrick larvae bore into tender buds, causing caterpillars to cover flowers and buds with webs, causing crop losses. *Latoia lepila*, a slug caterpillar, can be a serious pest (Babu *et al*., 2000).

Disease

Nursery seedlings are affected by powdery mildew caused by *Oidium sp*., causing defoliation and retarding early growth. Cercospora leaf disease attacks tamarind, causing severe defoliation and causing early growth retardation. In order to have effective control 3-4 sprays of wettable sulphur at 15-day intervals is the most economical method (Gatan, 2021). Seedling blight disease caused by *Macrophomina phaseolina* and *Rhizoctonia solani* is crucial during nursery stage. Raising seedlings in amended soils can reduce blight incidence (Muhammad *et al*., 2001).

Alternate Bearing

Regular bearing in cropping is not systematic, while alternate bearing is a genetic trait identified in tamarind trees. It can be managed through cultural practices and hormonal treatments (Singh, Mishra, *et al*., 2021).

Maturity index:

Flesh color varies from green to brown, dark brown, red, or black, depending on variety (Parthasarathy; *et al*., 2008). At maturity, exocarp hardens and separates from pulp. Finger pressing tamarind fruits produces a hollow, loose sound, indicating pulp shrinkage and fruit readiness for harvesting, while shell brittleness develops (Sudha *et al*., 2022).

Harvesting:

Tamarind trees can be propagated through seeds or vegetatively, with tamarind trees bearing fruits 8-12 years after planting. Economical yields can be achieved after 7-10 years, with a lifespan of 50-60 years. Flowering typically occurs from June to July, and fruits are mature and ready for harvest in India during summer (Nybe, 2007). Mature Fruits-Fully ripen fruits are harvested. They are used for the preparation of various products like Sauce etc., (P.C.Das, 2018). Fruits are harvested by shaking the branches and the fallen fruits are collected. During the second harvest the left-over fruits are picked using fruit picker. Mechanical innovations in fruit bunch picking include branch and trunk shakers, suited for hard trunk trees like tamarind and soft trunk trees like apricot.

Yield:

PKM 1 variety yields 250 kg per tree after 9 years, starting from 4-5 years, with grafts starting from 4-5 years (Prasath *et al*., 2019). A fully mature tree can produce 20 to 250 kg of fruits annually (P.C.Das, 2018).

Processing:

Tamarind can be processed using wet and dry methods, including drying, dehulling, defining, deseeding, pressing into cakes, and storage. It can also be pulped to remove seeds, fiber, and cellulose, creating edible pulp with minimal water. This pulp is then compacted into blocks similar to cheese and drum-dried (Sudha *et al*., 2022).

Drying:

(Sudha *et al*., 2022) Tamarind dehulling and deseeding are crucial for drying. A local type was dried in the sun and subjected to plate drying at 50, 60, and 70°C. Mechanical drying at 70°C increased dampness expulsion rate (P.C.Das, 2018). Tamarind requires deseeding and sun drying for pulp preservation.

Dehulling:

Tamarind can be dehulled by drying it completely in the sun and then removing the hull and pulp with sticks. The dehuller for tamarind was invented by TNAU, Coimbatore, India and has a deshelling rate of 100 kg/h, dehulling capacity of 94% (Pandian and Rajkumar, 2018).

The feed hopper was saturated with dried tamarind fruit, and rotating beaters applied impact force. Dehulled, un-hulling, and hull-less fruits were sent to the outlet. A dehuller was created at PHT center, UAS, Bangalore. Large curved fruits had a higher hulling percentage (79.48%), with a capacity of 500 kg per hour (Parthasarathy; *et al*., 2008).

Deseeding:

In Tamil Nadu, seeds are eliminated by hand beating tamarinds, A hammer type tamarind deseeder invented at Tamil Nadu Agricultural university (Sudha *et al*., 2022).

Tamarind seed processing:

Each tree produces 60–200 kg of seed. Which has numerous medicinal properties. There are three significant activities in Tamarind seed handling, roasting, decorticating and color sorting (Rao *et al*., 2015).

Roasting:

Tamarind seed is roasted in a horizontal cyclone furnace. The furnace is having temperature of 220℃ to brittle out the external layer of the tamarind seed (Feng *et al*., 2022).

Decorticating:

Roasted seed is shipped off the decorticator for eliminating the external layer of the seed. After decortications husk will be removed (ARUDRA, 2015).

Color sorting:

Variety sorters sort seeds based on their external layer (Testa) and internal tone (creamy white). Un-decorticated seeds are removed for decorticating activity (Rajkumar *et al*., 2023).

Value added products:

Tamarind seed Kernel Powder (TKP):

Tamarind seed Kernel Powder (TKP) is a pulverized tamarind used as an adhesive in the paper industry (Prabhu and Teli, 2014). Tamarind seed powder is widely used in vegetable and food industries for thickening, stabilizing, and gelling food through tamarind gum or tamarin xyloglucan.

Tamarind gum:

Tamarind gum is a user-friendly dye made by boiling tamarind seed powder in water, used for dyeing cotton and silk fabrics. This process is more efficient than solution dye preparation in powder form (Malviya *et al*., 2021).

Tamarind seed oil:

Tamarind seeds contain golden yellow oil about 7-9% oil content, used as a light and varnishing agent. Amber oil is also used (El-Siddig *et al.*, 2006).

Pulp based products:

Tamarind toffees:

Toffee is a sweetmeat made from fruit pulp and sugar, wrapped in paper or after fiber loss. Tamarind balls are a type of sweetmeat made from sugar and pulp in India (Singh *et al*., 2007).

Tamarind beverage:

Tamarind pulp is a popular beverage in southern and central America and Asia, used to create ready-to-serve drinks, syrups, and concentrates with a shelf life of six months. The pulp is mixed with water and hand squeezed for delicious drinks (Lima and Bolini, 2020).

Tamarind pulp powder (TPP):

TPP is an easy food product made by concentrating, drying, and milling pulp, with physicochemical characteristics varying depending on manufacturing method (Bhusari and Kumar, 2014).

Tamarind pickle:

Tamarind pickle is made from commercially available pulp. (Sudha *et al*., 2022) The flavor of pickles is hot, spicy, and salty, making them long-lasting. Salt, increased acidity, and spices are responsible for preserving (Singh *et al*., 2007).

Tamarind candy:

Tamarind candy is popular due to its natural sour-sweet flavor. It is made by boiling tamarind pulp with sugar and simmering it with minimal water. Sweetened tamarind fruit is prepared by peeling ripe fruits and pouring boiling sugar syrup at 62°C (Sudha *et al*., 2022).

Sous:

Traditional Jordanian drink made with tamarind, *Glycyrrhiza glabra* roots, and mulahatti and yastimadhu (Latoch and Libera, 2019).

Tamarind Ade:

The perfect blend of ripe pulp with sugar and water is used to make this delicious tamarind drink, which is also made in the Philippines and many tropical American countries (Sudha *et al*., 2022).

Tamarind juice concentrate:

Tamarind pulp is extracted from pods, separated juice, and hand-pulled into pulp, ensuring purity and free from contaminants (Maia *et al*., 2021).

Tamarind jam:

Tamarind jam is made by shelling ripe fruits, boiling pulp at 100°C for 10 minutes, cooling, packing in sterile jars, and sealing (Singh *et al*., 2007).

Tamarind fruit leather:

The soft, rubbery and sweet taste of fruit leather is a result of drying sheets of tamarind fruit pulp (Sudha *et al*., 2022). Study examines drying techniques on tamarind leather, revealing that cabin drier and solar drier affect color.

Storage:

The moisture content during storage dropped from 30% to approximately 20% (KUMAR *et al*., 2018). Compared to storage in white polythene wrap, and plastic containers, the initial brown color might continue up to 4 months in metal and black polythene (Parthasarathy; *et al*., 2008).

Conclusion

Tamarind production technology is essential for sustainable growth and development. Innovative practices like intercropping and agroforestry optimize land utilization, conserve resources, and promote biodiversity. Water-efficient irrigation systems overcome challenges, and variety selection improves productivity. Integrated pest management protects trees, and efficient post-harvest practices preserve nutritional content. Product diversification enhances revenue streams and attracts investors. Eco-friendly techniques promote responsible tamarind production, aligning with global sustainability goals.

References

Abdel Moneim E. Sulieman , Salwa M. Alawad , Magdi A. Osman , and Abdelmageed, E. A. (2015). Physicochemical Characteristics of Local Varieties of Tamarind (*Tamarindus indica* L), Sudan, . *Int. J.Plant Res.*, *5* (1):13-18.

ARUDRA, A. K. (2015). Tamarind seed processing and by-products. *Agricultural Engineering International: CIGR Journal*, *17*(2).

Ashvini V Joshi, Aware Urmila, and, G. S., and Shahrukh., S. (2023). Review on *Tamarindus indica. J Pharmacogn Phytochem 12*(1):303-308.

Azad, S. (2018). Tamarindo—Tamarindus indica. In S. Rodrigues, E. de Oliveira Silva, and E. S. de Brito (Eds.), *Exotic Fruits* (pp. 403-412).

Azhakiamanavalan, R. S., and Vadivel, E. (1997). Dryland tamarind PKM-1: Pre and post released status. Proc. Nat. Sym. On tamarind (*Tamarindus indica* L.) held at Tirupathi (A.P.) organized by Department of Forest, Government of Andhra Pradesh, India.

Babu, A., Sheeba, G., Sen, A., and Ignacimuthu, S. (2000). Record of slug caterpillar on Ixora parviflora Vahl. *Insect Environment*, *6*(1):19.

Bennet, S., Durai, A., Nicodemus, A., Gireesan, K., Nagarajan, B., and Varghees, M. (1997). Genetic improvement of *Tamarindus indica* L. for increased productivity. Proceedings of National Symposium on *Tamarindus indica* L. Tirupati, Andhra Pradesh, India.

Bhusari, S. N., and Kumar, P. (2014). Antioxidant activities of spray dried tamarind pulp powder as affected by carrier type and their addition rate. International Conference on Food, Biological and Medical Sciences (FBMS-2014), Bangkok (Thailand).

Chimsah, Francis and Nyarko, George and Abubakari, Abdul-Halim. (2020). A review of explored uses and study of nutritional potential of tamarind (*Tamarindus indica* L.) in Northern Ghana. African Journal of Food Science. 14(9):285-294..

Choudhary, B., and Dongre, R. (2022). Production Technology of Tamarind (Tamarindus indica L.). *A Monthly Peer Reviewed Mag.Agri. Allied Sci.*, 1(10):57.

Coronel, R. E., 1991. *Tamarindus indica* L.. In: Verheij, E.W.M. and Coronel, R.E. (Editors). Plant Resources of South-East Asia No. 2: Edible fruits and nuts. Pudoc, Wageningen, The Netherlands, pp. 298-301.

De Lima Neto, A. J., Cavalcante, L. F., Nunes, J. C., de Luna Souto, A. G., Bezerra, F. T. C., and Cavalcante, A. G. (2018). Biometric variables and photosynthetic pigments in tamarind seedlings irrigated with saline water and biofertilizers. *Semina: Ciências Agrárias*, *39*(5):1909-1920.

Devi, B., and Boruah, T (2020). Tamarind (*Tamarindus indica*). In, pp. 317-332.

El-Siddig, K., Gunasena, H. P. M., Prasad, B. A., Pushpakumara, D. K. N. P., Ramana, K. V. R., Vijayanand, P., and Williams, J. T. (2006). Tamarind, *Tamarindus indica*. *Crops for the Future*, pp- 188.

Emmy De Caluwé, K. H. P. V. D. (2010). Tamarindus indica L. – A review of traditional uses, phytochemistry and pharmacology. *Afrika Focus*, *23*(1):53-83.

Fandohan, Adandé and Salako, Valère and Assogbadjo, Achille and Diallo, Boukary and Van Damme, Patrick and Brice, Sinsin. (2015). Effect of climatic conditions on flowering and fruiting of Tamarindus indica (Fabaceae). *J Horti. Fores.*, 7:186-192.

Farooqi;, A. A., Sreeramu;, B. S., and Srinivasappa, K. N. (2005). *Cultivation of Spice Crops*. Pp-396.

Feng, L., Liu, H., Li, L., Wang, X., Kitazawa, H., and Guo, Y. (2022). Improving the property of a reproducible bioplastic film of glutenin and its application in retarding senescence of postharvest *Agaricus bisporus*. *Food Biosci.*, *48*:101796.

Feungchan, S., Yimsawat, T., Chindaprasert, S., and Kitpowsong, P. (1996). Effect of plant regulators in fruit setting Thailand. *J. Agril. Set*(Special issue (1):48-51.

Gatan, M. G. (2021). Identification and assessment of major phytopathogenic fungi of tamarind leaves in Central Luzon, Philippines, *Pampanga State Agricultural University Philippines*.

Geetha, V. (1995). Urigam tamarind-A unique variety. *Spice India*, *8*(8), 8-9.

Gunasena, H. P. M. (1999). *Tamarind, an unexploited species in Sri Lanka.* Paper presented at the National Workshop on Fruits for the Future. , Gannoruwa, Sri Lanka. 4 November. Gannoruwa, Peradeniya, Sri Lanka.

Hamacek, F., Santos, P., Cardoso, L., and Pinheiro-Sant'Ana, H. (2013). Nutritional composition of tamarind (*Tamarindus indica* L.) from the Cerrado of Minas Gerais, Brazil. *Fruits*, *68*:381-395.

Hernandez-Unzon, H., and Lakshminarayana, S. (1982). Developmental Physiology of Tamarind Fruit (Tamarindus indica L.) 1. *HortScience*, *17*(6): 938-940.

Hocking, D. (1993). *Trees for Drylands. Tamarindus indica L., Family Leguminosae: Caesalpi-noideae.* Oxford and IBH Publishing Co., New Delhi.

Idris, M., Karamba, H., and Ayoubi, R. (2018). Tamarindus indica. - A Review Paper on Efficacy of Tamarind plant in Water Treatment and Purification. *Int.J..Sci.Eng. Res*., 9(10):2024-2035.

Ishaku, G., Ardo Pariya, B., Hayatuddeen, A., and Andrew, F. (2016). Nutritional Composition of Tamarindus indica fruit pulp. *J. Chem.Chemical Sci.*, *6*:695-699.

Jøker, D. (2000). Tamarindus indica L. *Seed Leaflet-Danida Forest Seed Centre* (45) pp-2.

Joshi, A. V., Urmila, A., Swapnil, G., and Shahrukh, S. (2023). Review on *Tamarindus indica. J.Pharm. and Phytochem.*, *12*(1):303-308.

Joshi, R., and David, V. (2018). Nemataode, mite and insect pests of tamarind: A review, Agri.for Dev., 35(6):52-63.

Karale, A., Kavlgud, S., and More, T. (1997). Studies of tamarind in Maharashtra. Proc. Nat. Symp. on Tamarindus indica L., Tirupathi (AP), Organized by Forest Dept. of AP, India.

Karale, A., Wagh, A., Pawar, B., and More, T. (1999). Association of fruit characters in tamarind. *J-maharashtra agri. univ.*, *24*(3):319-320.

Karale, A.R (2000). A research report on tamarind, presented at Research Workers Group meeting of AICRP on Arid Zone Fruits held at ANGRAU, Rajendranagar, Hyderabad, 13-15.

Kelly, B., and Cuny, P. (2000). Afforestation using indigenous forest tree species on hydromorphic soil. Results of an experiment in southern Mali. *Revue Forestière Française*, *52*(5):453-466.

Keskar, B., Karale, A., Dhawale, B., and Choudhari, K. (1989). Improvement of Tamarind (Tamarindus indica L.) by selection. *Maharashtra J. of Hort.*, *4*(2), 121-124.

KUMAR, B., PATEL, S., and MISHRA, N. (2018). A Review on-Post Harvest Handling Practices of Tamarind (*Tamarindus indica* L.) Fruits. *Trends in Biosciences* 11(5): 565-567.

Kumar, Sunil and Thombare, Pratibha and Kale, Pandurang. (2020). Tamarind: Value Added Products and its Health Benefits, *AGRI. and FOOD* e-Newsletter,2(3):93-95.

Latoch, A., and Libera, J. (2019). Quality and safety of pork steak marinated in fermented dairy products and sous-vide cooked. *Sustainability*, *11*(20):5644.

Lima, R. S., and Bolini, H. M. A. (2020). Impact of non-nutritive sweeteners on the sensory profile and acceptance of a functional tamarind beverage. *J. Food and Nut. Res.*, *8*(1):26-32.

Lokesh, A. R., Sarala, B. S., and Chavan, R. (1997). Evolutionary significance of style orientation in Tamarindus Indica 1. and possible evolutionary constraints for low reproductive success. Proceedings of the National Symposium on *Tamarindus indica* L. , Forest Dept., Tirupathi, Andhra Pradesh.

Lu, M., Yuan, B., and Chen, J. (2011). Antioxidant capacity and major phenolic compounds of spices commonly consumed in China. *Food Res. Int.*, *44*:530-536.

MacDonald, I., Omonhinmin, A., and Ogboghodo, I. (2002). Germination ecology of two savanna tree species, *Tamarindus indica* and *Prosopis africana*. *Seed Tech.*, 103-107.

Maia, J. L., Wurlitzer, N. J., Lima, J. R., Borges, M. d. F., Maia, M. d. O., Damião, B. S., and Oliveira, L. d. S. (2021). Quality and storage stability of tamarind juice. *Brazilian Journal of Food Technology*, *24*:1-9.

Malviya, R., Sundram, S., Fuloria, S., Subramaniyan, V., Sathasivam, K. V., Azad, A. K., Sekar, M., Kumar, D. H., Chakravarthi, S., and Porwal, O. (2021). Evaluation and characterization of tamarind gum polysaccharide: the biopolymer. *Polymers*, *13*(18):3023.

Martin, I. (2007). Fruits for the Future. 1. Revised edition. Tamarind. (*Tamarindus indica* L.) By K. El-Siddeg, H. P. M. Gunesana, B. A. Prasad, D. K. N. G. Pushpukumara, K. V. R. Ramana, P. Vijayananand and J. T. Williams. Southampton, UK: Southampton Centre for Underutilized Crops (2006). *Exp agr*, *43*:188.

Mayavel, A., Prasath, C. H., Muthuraj, P., and Nagarajan, B. (2018). Effect of Manuring, Growth Regulators and Chemicals on Vegetative and Reproductive Characters of Seed Origin Plantation in Tamarind (*Tamarindus indica*). *Int. J. Curr. Microbiol. App. Sci*, *7*(10):1821-1826.

Meena, Vijay Singh, Jagan Singh Gora, Akath Singh, Chet Ram, Nirmal Kumar Meena, Pratibha, Youssef Rouphael, Boris Basile, and Pradeep Kumar (2022). Underutilized Fruit Crops of Indian Arid and Semi-Arid Regions: Importance, Conservation and Utilization Strategies. *Horticulturae*, *8*(2):171.

MGanga;, and Balakrishnamoorthy, G. (1997). *In vitro rhizogenesis axillary buds derived micro shoots of the tamarind genotype "Urigam".* proceedings of the national symposium on Tamarindus indica L. Forest Dept., Tirupathi, Andhra Pradesh.

Morton, J. (1987) Fruits of Warm Climates. J.F. Morton, Miami, Chapter Mango *Mangifera indica* L.

Mowobi, G. G., Osuji, C., Salisu, A., and Yahaya, F. M. (2016). In vitro regeneration of Tamarind (*Tamarindus indica* L.) explants. *J. Env and Life Sci 1*(1): 26-31.

Muhammad, S., and Amusa, N. (2003). Effects of sulphuric acid and hot water treatments on seed germination of tamarind (*Tamarindus indica* L). *Afr J. of biotech.*, *2*(9):376-279.

Muhammad, S., Suberu, H., Amusa, N., and Agaji, M. (2001). The Effect Of Soil Amendment with Sawdust and Rice Husks on the growth and incidence of seedling blight Of Tamarrindus indica Linn caused by by *Macrophomina phaseolina and Rhizoctonia solani*. *Moor J. Agric. Res*, *2*:40-46.

Murthy, K. (1997). Tamarind tree improvement works in Karnataka. *My forest*, *33*:457-464.

Muzaffar K, Kumar P. (2017),Tamarind-a mini review. *MOJ Food Process Technol*.;5(3):296-297

N.Shinde;, N., and L. V. Kulval. (1995). Variability studies in tamarind. Proceedings of National Symposium on advance in research and development in Horticulture for export, Hissar.

Narina, S. S. S., and Catanzaro, C. J. (2018). Tamarind (*Tamarindus indica* L.), an Underutilized Fruit Crop with Potential Nutritional Value for Cultivation in the United States of America: A Review. . *Asian Food Sci.J.*, *5*(1):1–15.

Ndiate, N. I., Qun, C. L., and Nkoh, J. N. (2022). Importance of soil amendments with biochar and/or Arbuscular Mycorrhizal fungi to mitigate aluminum toxicity in tamarind (*Tamarindus indica* L.) on an acidic soil: A greenhouse study. *Heliyon*, 8(2):1-11.

Nybe, E. V., Mini Raj, N., and Peter, K. V. (2007). Spices. In K. V. Peter (Ed.), *Horticulture Science Series* 5:159-164.

Okello, J., Okullo, J. B., Eilu, G., Nyeko, P., and Obua, J. (2017). Mineral composition of *Tamarindus indica* LINN (Tamarind) pulp and seeds from different agro- ecological zones of Uganda. *Food sci and nutri*, *5*(5) 959-966.

Olomola, D., Osunlaja, O., Adekunle, E., Kolawole, I., Aguda, S., and Oyediran, R. (2019). In-vitro propagation of Tamarindus indica L. through Seed Culture Technique towards Plantation Establishment. *In-vitro*, *5*(11):213-219.

P.C.Das. (2018). Spice Crops Production Technology. *Sci. Publishers*.

P.N.Ravindran, Nirmal Babu, K., Shiva, K. N., and Kallupurackal, J. A. (2006). Advances in Spices Research: History and Achievements of Spices Research in India Since Independence. *Agrobios*, Jodhpur.

Pandian, N.K.S. and P. Rajkumar. 2018. Harvest and Postharvest Processing of Tamarind. Tamarind Science and Technology, *Scientific Publishers* (India), 41 -51..

Parameswari, K., Srimathi, P., and Maiarkodi, K. (2001). Standardisation of dormancy breaking treatment in tamarind (*Tamarindus indica* L.) seeds. *Legume Research-An International Journal*, *24*(1):60-62.

Pareek, O., and Awasthi, O. (2002). Genetic resources of tamarind. *I.J. of Plant Gen Res.*, *15*(3):197-202.

Parthasarathy;, V. A., Parthasarathy;, U., and Kumar, A. (2008). *Spice Crops: Vol: II: Tree Spices*. Today and Tomorrow, New Delhi.

Parvez, S. S., Parvez, M. M., Nishihara, E., Gemma, H., and Fujii, Y. (2003). Tamarindus indica L. leaf is a source of allelopathic substance. *Plant Growth Reg*, *40*(2):107-115.

Prabhu, K., and Teli, M. (2014). Eco-dyeing using Tamarindus indica L. seed coat tannin as a natural mordant for textiles with antibacterial activity. *J of Saudi Chem Soci*, *18*(6):864-872.

Prasath, C. H., Balasubramanian, A., and Radhakrishnan, S. (2019). Effect of Canopy Management (Pruning) on Fruit Yield in Tamarind Plantation at Harur Taluk, Dharmapuri, Tamil Nadu, India. *Ind J. of Plant and Soil*, *6*(1).

Pruthi, J. S. (2001). Minor spices and condiments: crop management and post-harvest technology. Bio-Green Books

Purseglove, J. (1987). Tropical Crops: Dicotyledons Longman Group Ltd. *Burnt Hill*.

Rachie, K. O. (1979). Tropical legumes: resources for the future. *Tropical legumes: resources for the future.*

Raja, M. M., Poonguzhali, S., Rao, B. V., Choudhury, A., and Devarajan, A. (2022). A Scientific Evidence-based Review of Tamarind usage in Indian Folklore Medicine. *J. Nat. Remed*, 347-362.

Rajamanickam C, Baskaran A, Ravindran C, Sundaraiya K, and V, V. (2023). Genetic diversity in tamarind (*Tamarindus indica* L.) *The Pharma Inno J.*, *12*(5): 1921-1926.

Rajamanickam, D. C. (2020). Genetic variability, correlation and path analysis in tamarind (Tamarindus indica L.). . *J.of Spices and Aromatic Crops.*, 133-139.

Rajkumar, P., Deepa, J., and Rani, C. I. (2023). Mathematical Modeling on Drying of Tamarind Fruits. *J. Sci. and Ind Res.*, 82(6):661-670.

Rao, A. S., Kumar, A. A., and Ramana, M. (2015). Tamarind seed processing and by-products. *Agric. Eng. Int.: CIGR J*, *17*:200-204.

Rao, L., Joseph, B., and Sreemannarayana, B. (2000). Growth and biomass production of some important multipurpose tree species on rainfed sandy loam soils. *Indian forester*, *126*(7):772-781.

Rao, Y. S., and Mathew, K. M. (2012). Tamarind. In *Handbook of herbs and spices Elsevier*.pp. 512-533.

Ravindran, P. (2006). Advances in spices research. *Agrobios* (India).

Reena, J., and Bagyaraj, D. (1990). Growth stimulation of Tamarindus indica by selected VA mycorrhizal fungi. *World J. of Microbio and Biotech.*, *6*:59-63.

Sambandamoorthy, S., and Vadivel, E. (1996). Growing tamarind in dry land. *The Hindu*.

Shah, N. (2014). Tamarindus indica – Introduction in India and Culinary,Medicinal, and Industrial Uses *Asian Agri-History 18*(4), 343-355.

Shankaracharya, N. B. (1998). Tamarind - chemistry, technology and uses - a critical appraisal. *J.of Food Sci and Tech.-mysore*, *35*:193-208.

Sharma, S., and Bhardwaj, R. (1997). Tamarind–a suitable fruit crop for dry arid regions. *Proc. Nat. Sym. on Tamarindus indica*, 4-6.

Singh, D., Wangchu, L., and Moond, S. K. (2007). Processed products of Tamarind. *Natural Product Radiance*, *6*:315-321.

Singh, S., Mishra, D., and Singh, A. (2021). Tamarind (*Tamarindus indica* L.). *Tropical Fruit Crops Theory to Practical*, 610-631.

Singh, S., Naruka, I., and Singh, A. (2021). Tamarind (*Tamarindus indica* L.). pp. 439-456.

Sookying, S., Duangjai, A., Saokaew, S., and Phisalprapa, P. (2022). Botanical aspects, phytochemicals, and toxicity of Tamarindus indica leaf and a systematic review of antioxidant capacities of T. indica leaf extracts.*Frontiers in Nutrition*, *9*.

Srinivasarao, A., and Kumar, A. (2015). Tamarind seed processing and by-products. *Agricultural Engineering International : The CIGR e-journal*, *17*:200-204.

Sudha, P., Rajkumar, P., Joice, A. A., Sudagar, I. P., and Arulmari, R. (2022). Postharvest Technology of Tamarind. In A. Md (Ed.), *Postharvest Technology* .pp. Ch. 8

Suresh, J., V;, S., V;, P., and I, I. (1992). Tamarind – a tree for wasteland. . *Spice India 5(12)*, 2-3.

Tania, C., Das, M., Basanta, T., Chatterjee, R., Hnamte, V., and Chattopadhyay, P. (2018). Assessment of Tamarind (Tamarindus indica L.) Varieties for Growth, Flowering, Fruiting, Yield and Quality. *Int. J. of Curr Micro and App Sci*, *7*(11):1708-1713.

Usha, K. (1987). Studies on pollination biology of tamarind in relation to its productivity, *Mydre J. Agril. Sci.*, 21-107.

V.Kulwall;, S. Taydeg, M.H.Chaudari, and R.MVerma. (1997). *Soft wood grafting - an easy method of propagation of tamarind. Linn.*

Venkataravana, P., Sivappa, M. M., and Priyadarshini, S. (2020). GKVK-17: A new high yielding variety of Tamarind (Tamarindus indica L.) for Southern region of Karnataka. *IJCS*, *8*(1), 1883-1886.

Yaacob, O., and Subhadrabandhu, S. (1995). *The production of economic fruits in South-East Asia*. Oxford University Press.

Yahia, E. M., and Salih, N. K. E. (2011). 22 - Tamarind (Tamarindus indica L.). In E. M. Yahia (Ed.), *Postharvest Biology and Technology of Tropical and Subtropical Fruits* pp. 442-458. Woodhead Publishing.

Yusuf, A., Mofio, B., and Ahmed, A.-B. (2007). Proximate and Mineral composition of Tamarindus indica Linn 1753 Seeds. *Sci. World J.*, *2*, 1-4.