Genetic Resources of Tamarind

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The tamarind tree has gained great socio-economic significance in a large part of the globe. It yields a large number of economic products from the fruit pulp and the seed, besides the usage of almost all its plant parts either as timber, fuel, vegetable or medicine. Introduced into the Indian sub-continent during pre-historic days, a wide genetic diversity of tamarind is found in India. The paper provides information on the diversity regions, extent of variability with respect to growth and fruit characters, germplasm holdings, evaluation and selection of genotypes, etc. A scheme of classification of tamarind types based on fruit characters and ideotype description to aim at genetic improvement for commercial exploitation have been suggested.

Key Words: Diversity, Genetic Resource, Germplasm, Tamarind

Tamarind (*Tamarindus indica* Linn.), a truly pantropical tree, is highly drought hardy and can be grown in dryland areas and on degraded, eroded, gravelly, saline and sodic wastelands. Optimum annual rainfall for tamarind is over 750 mm, but it is also found to thrive in regions receiving less than 500 mm rainfall. It can also be grown in localities subject to high winds because of its strong and pliant branches. Thus it is one of the most suitable tree as a windbreak to prevent soil erosion and to protect people, crops and animals in harsh environments.

The tamarind tree has great commercial importance owing to the usefulness of almost all its parts, *i.e.* the leaf, flower, fruit and wood. Its fruit has the greatest value. The fruit contains 43 to 73% edible pulp, 12-40% seed and 11 to 25% shell and fibre. The pulp is very nutritious being rich in calcium, phosphorus, riboflavin, niacin and thiamine (Table 1). Tartaric acid and invert sugars are the major constituents of the pulp. Of the invert sugars, 70% is glucose and 30% is fructose with only a trace of sucrose. A large number of products are prepared from the fruit pulp. Young tamarind seeds contain 10-15% (by weight) amber, sweet-tasting oil (Allen and Allen, 1981). This high quality oil is used in varnishes and paints, for finishing Indian cloth, and as an illuminant. In India and South-east Asia, tamarind seeds are also crushed and boiled to produce a paste that is used as a roofing material. This material is highly resistant to corrosion by salt sprays from sea waters.

Tamarind kernel powder (TKP) contains nearly 60% jellose (Savur and Sreenivasan, 1948) which can be used as a substitute of fruit pectin (Table 1). The TKP is also of great value as a sizing material for cotton and jute yarn. The immature leaves are used to garnish curries and vegetable preparations. The tree is, therefore, of considerable commercial value besides its use as an avenue tree or for rehabilitation of marginal lands.

Diversity Regions

The tamarind is native of tropical Africa and Asia (Bailey, 1949), although the species name *indica* gives an illusion of it being of Indian origin. In fact, Watt (1898) had suggested that tamarind is native to some parts of south India. Tamarind is found in wild form in extensive areas of Africa particularly Ethiopia and Sudan which is believed to be its native home and from where it disseminated throughout the tropics. It reached India and South-east Asia, perhaps during the pre-historic times, where it got naturalized.

Tamarind occurs throughout the tropics and subtropics covering the Caribbean, Central American, South American, European, African, South Central Asian, South-East Asian and Oceania regions. It occurs in wild form all over Central Africa from Senegal in the west through Ghana, Niger, Nigeria, Sudan to Ethiopia in the east and then southwards to Tanzania and Zimbabwe and extending eastward into the Reunion Islands (Fig. 1). It is also found wild in southern India, Sri Lanka in South Asia and in the Philippines, Malaysia, Thailand, Fiji and New Caledonia islands in South-East Asia. Another important diversity region extends from Mexico through central America and the Caribbean region into South American parts of Ecuador, Peru, Colombia, Puerto Rico, Costa Rica, Venezuela and Brazil.

In India, tamarind largely occurs in the peninsular region mainly in the districts of Dharmpuri, Kamrajar and Kanyakumari in Tamil Nadu; in Chintamani and Srinivaspur regions of Karnataka; in Sholapur, Osmanabad, Satara, Sangli, Ahmednagar, Nasik and Aurangabad districts in Maharashtra; and in Bastar in Chhattisgarh (Fig. 2). However, its trees can be found

Table 1. Composition of tamarind pulp, seed, immature leaves and flower

Constituents	Pulp (ripe)	Seed	Young leaves	Flower
Moisture (%)	17.8-69.0	9.4-11.3	70.5-78.0	80.0
Protein (%)	1.3-3.10	13.3-26.9	4.0-5.8	0.45-2.8
Lipid (%)	0.40-0.80	–	–	–
Fat (%)	0.10-1.00	4.5-16.2	1.2-2.1	1.54
Fibre (%)	2.9-5.6	7.4-8.8	1.9-3.0	–
Carbohydrate (%)	41.1-71.8	50.0-61.7	16.0-18.2	1.5
Ash (%)	1.5-4.2	1.6-4.2	1.0-1.5	0.72
Calcium (mg/100 g)	34-170	–	101-250	35.5
Magnesium (mg/100 g)	–	–	71.0	–
Phosphorus (mg/100 g)	34-110	–	140.0	45.6
Iron (mg/100 g)	0.2-10.9	–	2.0-5.2	1.5
Copper (mg/100 g)	–	–	2.0-2.1	–
Chlorine (mg/100 g)	–	–	94.0	–
Sodium (mg/100 g)	24	–	–	8.0
Potassium (mg/100 g)	375	–	–	270.0
Sulphur (mg/100 g)	–	–	63.0	–
Vitamin A	151 IU	–	250 IU	–
Thiamine (mg/100 g)	0.3-0.59	–	0.24	0.072
Riboflavin (mg/100 g)	0.07-0.18	–	0.17	0.148
Niacin (mg/100 g)	0.6-12.0	–	1.5-4.1	1.14
Ascorbic acid (mg/100 g)	0.07-44	–	3.0-6.0	13.8
Tartaric acid (%)	8-28	–	–	–
Total acidity (%)	17.1-18.4	–	–	–
Cellulose (%)	1.8-3.20	–	–	–
Pentose (%)	4.2-4.8	–	–	–
Total sugar (%)	4.4-21.4	–	11.3-25.3	–
TSS (°Brix)	15.5-88.0	–	–	–
Pectin (%)	2.4-4.4	–	–	–
Energy Kcal/100 g	230-272	340.3	75.0	–
Starch (%)	–	33.1-63.0	–	–
In vitro protein digestibility (%)	–	71.6	–	–
Oxalic acid (mg/100 g)	Trace	–	196.0	–

Source: Pratt and Rosario (1913), Padilia and Solivan (1933), Maranon (1935), Galang (1955), Anon (1944), Lewis *et al.* (1954), Mitra and Misra (1967), Intengen (1968), Shanmugavelu and Rangaswami (1969), Anon (1972), Anon (1982), Morton (1987), Keskar *et al.* (1989)

all over the country extending northwards up to the Himalayas and eastwards into West Bengal and Assam plains along the water courses.

Germplasm Collections

The FAO-World Information and Early Warning System on Plant Genetic Resources lists 16 institutions holding 99 germplasm accessions of tamarind. Some of the collections are in Burkina Faso (9 wild/weedy accessions), Costa Rica (1), Ethiopia (5), France (2), Ghana (1), Honduras (1), Mexico (2), Philippines (12), Senegal (2), El Salvador (1), Taiwan (1) and USA (10). In India, there is a wealth of tamarind variability particularly in central and southern regions. However, systematic efforts have not been made so far to collect and evaluate this germplasm. The organizations holding tamarind germplasm in India have been listed in Table 2.

Conservation of elite trees for commercial exploitation has, thus, been done in several countries of the world. Clonally propagated systematic plantations have also been done. Even then, concerted efforts are necessary to conserve its genetic resources. It is equally important that methods and programmes are also developed to systematically evaluate these collections. This should include description using the standard descriptors including the important economic characters besides biochemical characteristics wherever relevant.

Variability in Plant Characters

Tamarind is essentially a cross pollinated crop (Thimmaraju *et al.*, 1977). As a result of cross pollination, seedling plants depict heterozygosity in morphological and physiological traits of the tree (Table 3). The height of tree varies from 25 to 30 m (Chaturvedi *et al.*, 1985) and at breast height maximum diameter from 1 to 4 m (Gamble, 1922). Tree longevity varies from 150 to 200 years (Anon., 1991).

Phenological variations in flowering and fruit maturity have also been reported (Mahadevan, 1991). Similarly, phenotypic variations have been observed in fruit characters such as pod weight, seed and pulp content, colour and taste of pulp, endocarp colour, etc. (Table 4).

Table 2. Tamarind germplasm collections conserved field genebanks in India

Centre	Number
State Agricultural Universities	
Belgaum, Karnataka	40
University of Agriculturel Sciences, Bangalore	19
Aurangabad, Maharashtra	351
Kovilangulam, Kamarajar, Tamil Nadu	26
Periyakulam, Tamil Nadu	85
Rahuri, Ahmednagar, Maharashtra	14
Pune, Maharashtra	118
Parbhani, Maharashtra	3
IGAU, ZARS, Jagdalpur	5
Bastar, Chattisgarh	
Forest Department, Karnataka	
Gottipura, Bangalore	40
Challekere RF, Bellary	50
Bidar	10
Yeregera, Raichur	10
Gungurgatti, Dharwad	70
Other stations in Karnataka	40
Forest Department, Tamil Nadu	
Coimbatore	40
Sesanchavady, Salem	61
Athivur, Erode	5
Varattupallum, Erode	4
Harur, Dharampuri	28
Ramanahalli, Dharampuri	23
Chengam, Tiruvaannamalai	52
Karumbapatti, Salem	77
Varinchipuram, Vellore	38

Table 3. Variability in tree characters in *Tamarindus indica*

Character	Range
Tree height (m)	5-34
Trunk girth (m)	1.5-7.0
Tree spread (m)	2.9-12.6
Tree volume (m^3)	50-1640
Number of leaflets	20-40
Fruit yield/tree(kg)	50-1500
Regularity in bearing (on:off year yields) (kg)	1:1-3 to 16:1

Source: Chaoji (1995), Hooker (1979)

Wide range of variability in morphological and physico-chemical characters of fruit has been observed in Maharashtra (Keskar *et al.*, 1989; Shinde *et al.*, 1995), Karnataka (Samiullah and Sheriff, 1973; Shivanandan, 1980; Challapalli, 1990), Andhra Pradesh (Mastan *et al.*, 1997) and Chhattisgarh (Awasthi and Sharma, 1998). Such variations in tamarind germplasm has been attributed to geographic isolation and gene mutation (Feungchan *et al.*, 1996).

Tamarind Types

Based on fruit characters, attempts have been made to designate different tamarind types. Lewis *et al.* (1954) recognized dark brown, brown, brownish red and light red types. Later they regrouped these into two types,

Table 4. Variability in morphological characters of fruit in *Tamarindus indica*

Characters	Range
Fruit weight (g)	8.9-63.6
Fruit length (cm)	8.2-32.0
Fruit, width (cm)	2.7-5.0
Curvature in pod	Straight, Curved
Bulging in pod	Flat, Bulged, Cylindrical
Pulp content (%)	24-71
Seed number/fruit	3.3-12.0
Seed content (%)	12-48
Rag and shell content (%)	11-42
Pulp colour	Red-Brown-Yellow
Endocarp colour	Extra white, White, Yellow
Seed length (mm)	0.95-1.8
Seed width (mm)	0.60-1.2
Seed weight (g)	2.6-12.5
Fruits (kg)	15-59.0
Seeds (kg)	517-1400

Source: Keskar *et al.* (1989), Chaoji (1995), Mastan *et al.* (1997)

one having rose red pulp and the other common type having light brown pulp. Hernandez-Unzon and Lakshminarayana (1982) also reported two types: one with brown pulp turning dark brown on storage and the other with red pulp. Cowen (1970) reported one tamarind type having brown pulp colour and sour taste and the other with reddish pulp colour and sweet taste.

Tamarind types have also been designated based on fruit shape. Bailey (1947) recognized two types of tamarind, namely, East Indian type having long and narrow fruits containing 6-12 seeds and West Indian type with shorter and broad fruits containing 1 to 14 seeds. In addition, the other important type is Thailand tamarind with shorter pods and sweet pulp. Cowen (1970) has described three types of tamarind having sickle shaped pods, straight long pods and short pods. Paulos (1975) recognized two types of tamarind, one having long and cylindrical pods (*Valakatchi*) and the other producing short cylindrical pods. Shivanandan (1980) recognized four types of tamarind, namely, straight and bulged, straight and flattened, curved and bulged and curved and flattened. Of these, straight and bulged type had longer pods (16.4 cm). Keskar *et al.* (1989) observed three distinct types of tamarind: curved and bulged, straight and flat and straight and bulged. Kennedy *et al.* (1997) classified tamarind fruits into five groups: long and bold fruit, medium fruit, small fruit, curved and irregular fruit and sweet fruit. Thus, the main characters used to classify tamarind types are pulp colour and taste besides endocarp colour, pod length and shape. It is, therefore, suggested that classification of tamarind types may be done on the primary, secondary and tertiary levels, as described subsequently.

(i) Primary characters	*Pulp colour* (red, brown); *Endocarp colour* (white, yellow); *Pulp taste* (sweet, sub acid, acid).
(ii) Secondary characters	*Pod length* (large: > 20 cm; small: < 20 cm); *Pod width* (wide: > 5.0 cm; Narrow: < 5 cm).
(iii) Tertiary character	*Pod shape* (straight and bulged, straight and flattened, curved and bulged, curved and flattened).

Promising Selections

As a result of evaluation of germplasm, trees having high fruit yield and superior quality traits have been identified. Fifty-two high yielding tamarind trees in Chittoor and Anantapur districts were identified by the State Silvicultural Division, Tirupati, Andhra Pradesh, based on morphological and physico-chemical characters of the fruits. Trees in the age group of 18 to 200 years were found to bear flowers and fruits. Highest yield was recorded from a 200-year-old tree in village Begarlapalli. In Chittoor district (village Chengalapuram), the yields were obtained from a tree of 150 years age. Very large size fruits (63.6 g) with light brown pulp and almost white endocarp have been reported from Akkampalli and Mudndi villages of Anantapur district. A more than 200-year-old tree has been reported growing near Urigam, Tamil Nadu, which yields 2 tonnes of fruit/year bearing pods 30 cm in length and 6.25 cm in width.

In three tribal tracts of Bastar (Chhattisgarh), *viz.*, Bastar, Kanker and Dantewada, the fruit yield varied from 40-50 kg/tree in trees of 6-7 years to 150-200 kg/tree in trees of over 20 years. The fruit maturity in different trees varied from early March to late May. Physico-chemical analysis of fruits showed variability in length (5-30 cm), girth (2.0-4.0 cm) and weight (15-60 g) of pod, pulp content (30-70%), pulp:seed ratio (4.0-1.0), pulp colour (light brown, dark brown, reddish brown), endocarp colour (white), acidity (8-12%) and TSS (25-80%). Some promising tamarind selections as a result of evaluation at different institutions are listed below:

PKM 1 : It is a selection made at Horticulture College and Research Institute, Periyakulam. It is an early bearer. Grafts come to flowering three years after planting and give commercial yield from fifth year. Nine-year-old trees gave a mean yield of 263 kg. It is a green tamarind producing yellow pods, having 39% pulp, high acidity (17.1%) and ascorbic acid (3.9 mg/100 g pulp).

Urigam : It is a progeny of more than 200-year-old tree identified near Urigam by the Department of Horticulture, Tamil Nadu, which is reported to yield 2 tonnes of fruits/year. The average length of fruit is 30 cm and width is 6.25 cm. It is a red tamarind.

Pratisthan: The variety was released from Fruit Research Station, Aurangabad. It has 61% pulp, 12% seed, 27% shell and 7-9% acidity. It is a sour-sweet and red tamarind. A 10-year-old tree yields 300 kg fruit. Its pulp can be stored for long period.

No. 263 : The variety has been released from Fruit Research Station, Aurangabad. It is a regular bearing cultivar producing 6-10 quintal fruits/tree. The fruits have pinkish and light yellow pulp, and 18-19% acidity. Fruits are large. On an average 45 fruits weigh to 1 kg.

Yogeshwari : The variety has been released from Taluk Seed Farm, Ambajogai (Beed) in Maharashtra. The fruits are large and have red and sour-sweet pulp with 6-7% acidity.

DTS 1 : It is a selection identified at University of Agricultural Sciences, Dharwad, College of Horticulture, Arabhavi. The pods are straight having semi-curved shape, 23.6 cm length, 3 cm width, 19.5 g weight, 51% pulp and 13.6% acidity. It is a late variety and takes 310 days from fruit set to maturity.

DTS 2 : This is a selection made at University of Agricultural Sciences, Dharwad, College of Horticulture, Arabhavi. The pods are straight having semi-curved shape, 17.6 cm length, 2.6 cm width, 18 g weight, 53% pulp and 12.2% acidity. It is an early variety and the pods mature in 280 days after fruit set.

Sweet tamarind : The origin of sweet tamarind has been attributed to point mutation. It is also assumed that the rare trait of sweetness in tamarind may be governed by recessive genes (Fuengchan *et al.*, 1996). The sweet tamarind is found mostly in South-East Asia and India. One Thailand variety is known as Makham Waan (Morton, 1987). Several sweet fruited trees are found in Cavite, Laguna and Binan regions of Philippines. The pods are 7-10 cm long, 2-3 cm wide, 20-30 g in weight and having 4 to 7 seeds/pod (Villanueva, 1920). The Institute of Plant Breeding, University of the

Philippines, Los Baños has identified promising trees. A variety named Manilla Sweet is reported from Florida.

In India, a red fleshed tamarind having sweet pulp (TSS>85%) has been spotted in village Faraskot, Dantewada, Bastar district of Chhattisgarh (Awasthi and Sharma, 1998).

Genetic Improvement

The objective of improvement strategy should be to select or develop high yielding types producing large and straight pods having extra white endocarp and high content of pulp with high TSS from the two variability groups of tamarind, *i.e.* sweet red and sour yellow-brown. Similarly, trees having dwarf growth habit with loose and well-formed crown, precocious and regular bearing habit need to be identified. The following ideotype description for development of an ideal genotype is suggested:

Ideotype description of tamarind

Character	Ideotype
Root system	Deep
Crown	Loose with profuse branching
Tree canopy	Circular
Tree height	Dwarf
Resistance to stress	Drought and frost resistance
Bearing	Precocious (from 5th year); regular
Pulp colour	Red
Endocarp colour	White
Pod length	>20 cm
Pod width	>5 cm
Pod weight	>20 g
Pod shape	Straight and bulged
Pulp:seed ratio	4:1
Pulp TSS	>80%
Acidity in pulp	Acidic type : 10-15 %; Sweet type : 6-10%

Selection

Presence of a large natural variation both in vegetative and reproductive characters and occurrence of bud spots in tamarind offer ample chances for identifying promising genotypes (Bailey, 1947; Keskar *et al.*, 1989; Challapalli, 1990; Samiullah and Sheriff, 1993; Nagarajan *et al.*, 1999). The desirable ones could be subsequently propagated by vegetative methods. Studies have shown that mid and late flowering types produce higher fruit yields. Some of the fruit characters could be used as markers for high productivity as indicated by the studies of Shivanandan and Raju (1988) and Challapalli *et al.* (1995). The length of fruit was positively correlated with its weight, pulp content and seediness. The fruit thickness was negatively correlated with fibre and seed content.

Hybridization

No attempts have been made to develop improved cultivars by hybridization. However, reproductive biology and breeding system have been studied in five tamarind clones by Nagarajan *et al.* (1999). Controlled pollination studies indicate that tamarind is predominantly an out-crossing species with extremely low level of selfing. Open pollination fruit set is between 1 to 2%. Pollen sterility is very low. Flowers show strong entomophilous adaptations. Apomixis is absent and fruit shows colour dimorphism.

Flowering in tamarind can be early, mid-season or late (Usha and Singh, 1996). The duration of fruiting is the longest in late flowering trees and shortest in early flowering trees. In mid and late flowering trees cross pollination has been observed to be more while the early flowering trees are mostly self-pollinated. In Karnataka, flowering in tamarind occurs between the last week of March and mid June. Anthers dehisce between 9.00 and 11.00 h. In majority of trees (64%), one floral bud was observed to flower at random on every alternate day while in 33% trees there was regular flowering, *i.e.* at least one floral bud opened/ day. A period of 25 days was required for flowering to complete in any infloresence.

The ability of the tamarind tree to adapt to a wide range of agro-ecological conditions and high degree of usefulness of all its plant parts: fruit, seed, leaf and wood, both for domestic utilization as well as in industry merit concerted focus on exploitation of its rich genetic variability by systematic research strategies mainly on (i) Collection, characterization and conservation of genepools, (ii) Identification of provenances with desirable characteristics according to use through characterization and evaluation.

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