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Postharvest Technology of Tamarind

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Abstract

Tamarind is a multi-purpose long-lived tree with heavy drooping branches and thick foliage. The entire fruit consists of 55% pulp, 34% seeds, and 11% hull and fibers. The tamarind tree produces numerous elongated fruit pods in a season that encompasses its branches in myriad. Brittleness in shell, changes in testa color, and a hollow sound from fruit when finger pressed signify matured fruit of the tree. Postharvest operations involved in Tamarind are drying, dehulling, defining, deseeding, pressing into cake, and storage. These operations are carried out by traditional and mechanical methods. Tamarind dehullers and deseeders were developed with efficiencies of around 94% and 83% respectively to minimize the losses involved in manual handling. The intrinsic value of raw tamarind may be further more desirable through processing into value-added products.

Keywords: tamarind, drought conditions, fruit pods, harvesting, intrinsic value, processing

1. Introduction

Tamarind (*Tamarindus indica* L.) is a commercially important tree that can be found in many Asian, African, and South American nations. The tree can reach its full potential with a crown diameter of 12 m and a height of 25 m. It is perfect for dry and semi-arid climates, particularly in drought-prone locations that lasts for a long time. The tamarind tree is a low-maintenance tree that is easy to grow. It is largely devoid of major pests and illnesses, and it has a long life expectancy. It can live up to 80–200 years and produce 150–500 kg of pods [1]. Each pod has a firm outer shell that surrounds a deep brown mushy pulp that encases two to ten hard dark-brown seeds. The pulp is sticky, as it is highly hygroscopic. The tamarind pulp is high in sugar, ranging from 21% to 30%, and its hygroscopicity increases as the relative humidity rises at room temperature.

India is the world's greatest producer of tamarind, with 300,000 t projected to be produced each year. It's especially common in states like Madhya Pradesh, Bihar, and Andhra Pradesh, Karnataka, Tamil Nadu, and West Bengal. Thailand is the second greatest producer, with 150,000 t recorded in 1995, with the sweet variety accounting for the majority of tamarind [2]. Mexico is also on the list commercially produces tamarind to a volume of approximately 29,600 t per year (**Figure 1**).

Figure 1.
Tamarind tree, India.

2. Postharvest handling practices

2.1 Harvest operations

The yield of pods stabilizes about 15 years and can last up to 50 or 60 years. When tamarind fruits are finger pressed, a hollow and loose sound is generated, indicating that the pulp has shrunk with maturity and the fruit is ready for harvesting. Brittleness develops in the shell. Additionally, a change in testa color could signify matured fruit of the tree [3]. Individual fruits on the same tree mature at different periods, making it difficult to select the right one for which harvesting is required. Pods are picked at various stages of ripeness, depending on their intended purpose. The sour tamarind mature fruits are commonly sold in most nations. It can be obtained by shaking trees and gathering up fallen fruits. The fruits are usually allowed to ripe on the tree before being harvested, reducing the moisture content to around 20% [4]. If left unharvested, the pods can stay on the tree for over a year after flowering, and will inevitably descend. Fruits for immediate processing are frequently harvested by separating the pod from the stalk, leaving longitudinal fibers connected. Fungi and beetles in humid conditions, ripe fruit is more easily attacked, thus they should be harvested before they have reached full ripeness.

Trunk shakers and branch shakers are the few mechanical advancements in harvesting fruit bunches. Trunk shakers are best suited for trees that have soft trunks and branch shakers are best suited for trees that have hard trunks like tamarind. Nowadays, branch shakers are available at a 2.5 kW power level. A two-stroke petrol engine drives the shaker. This commercial branch shaker is similar to a brush cutter with a 2 m long hooked pipe at the end to hold the branches intact and the reciprocal action of the engine imitates the shaking action [5].

3. Engineering properties of tamarind

The understanding of physical and mechanical qualities aids in the analysis of its behavior during handling and the design of process equipment. The average value of properties such as moisture content, size, shape, bulk density, true density,

porosity, angle of repose, surface area, and coefficient of friction was determined for whole and dehulled tamarind (**Table 1**) [6].

4. The traditional method of tamarind processing

In general, tamarind processing is done using both wet and dry processes. Tamarind is usually processed in a dry manner, with the process of drying (the whole tamarind to avoid pulp sticking to the hull), dehulling, defining, deseeding, pressing into cakes, and storage being the most prevalent process. The dehulling of tamarind entails sun drying the harvested entire tamarind and then pounding the hull away from the pulp with sticks (**Figure 2**).

It is necessary to remove the seeds and it's one of the most essential and labor-intensive processes (**Figure 3**). In the northern region of Tamil Nadu, the current method of deseeding tamarinds is by the manual pounding of the vertically aligned fruits with a hammer or wooden mallet by female laborers (**Figure 4**). Tamarind is deseeded by hand pounding, where a stone mortar is coated with oil, usually castor oil, and a wooden pestle is used to exert impact stress. A knife or a long sharp needle is also used to remove the seeds. The traditional approaches are rough, unhygienic, labor intensive, and time-consuming. As a result, to make tamarind processing easier, state agricultural universities created and released machinery for the benefit of processors and to ensure hygienic practices in processing (**Figure 5**).

Engineering properties	Whole tamarind	Dehulled tamarind
Geometric mean diameter	33.87 mm	26.21 mm
Sphericity	0.33	0.28
Surface area	3000.18 mm ²	1904.98 mm ²
Bulk density	240.39 kg/m ³	612.24 kg/m ³
True density	469.59 kg/m ³	1182.41 kg/m ³
Porosity	48.80%	48.22%
Angle of repose	35.4°	39.4°

Table 1.
Engineering properties of whole and dehulled tamarind fruit.

Figure 2.
Labors beating the dried whole tamarind as part of dehulling.

Figure 3.
Women workers are deseeding tamarind.

Figure 4.
Defibering action.

Figure 5.
Pressing action of deseeded tamarind into rubber ring to form cake.

5. Drying of whole and dehulled tamarind

Dehulling and deseeding are the significant tasks in tamarind processing for which tamarind is exposed to drying to moderate the tenacity with physical and mechanical parts. A local variety of tamarind dried under the sun as shown (**Figure 6**) followed by plate drying at temperatures of 50, 60, and 70°C. Mechanical drying of tamarind at 70°C had a higher dampness expulsion rate followed by drying at 60°C and 50°C. The drying data for sun drying of tamarind was well fitted with Midilli et al. model.

6. Mechanization

6.1 Tamarind dehuller

A dehuller for tamarind was developed at Tamil Nadu Agricultural University (TNAU), Coimbatore, India (**Figures 7 and 8**). It has a capacity of 100 kg/h with dehulling productivity of 94%. The impact force and sieve shaking mechanism were used to develop the Tamarind dehuller. The impact force from the rotating beaters was applied to the dried tamarind fruit fed through the feed hopper. The outlet received the dehulled, un-hulled, and hulled fruits. The system includes sharp “L” shaped pegs made up of 15×3 mm size gentle steel level mounted on the focal shaft that encased with 20×5 mm mild steel oblong sieve [7].

6.2 Tamarind deseeder

A tamarind deseeder developed at Tamil Nadu Agricultural University with the principle of impact and simultaneous shear (**Figure 9**) is used widely in Krishnagiri and Dharmapuri districts of Tamil Nadu to deseed small-sized tamarinds. The deseeding efficiency of the machine is 83% and the cost is Rs. 20,000/– [6].

A hammer-type tamarind deseeder was created and evaluated at Kumulur, Tamil Nadu Agricultural University comprises a feeding roller with rubber lining, hammering mechanism, motor, and power transmission framework and casing to

Figure 6.
Sun drying of the whole tamarind.

Figure 7.
Tamarind dehuller developed at Tamil Nadu Agricultural University, Coimbatore.

Figure 8.
Tamarind dehuller developed at Tamil Nadu Agricultural University, Coimbatore.

help the mechanism. The machine work on the standard of impact and deseeding proficiency of the machine is discovered to be 79% at 5 rpm (0.06 m/s); the peripheral speed of feeding roller to deseed the tamarind at the moisture content of 22.5% on a dry basis gives minimal mechanical harm to seed (0.3%) and pulp (14.94%). The equipment suits the large-sized fruits with multiple seeds. Feeding of small-sized fruits with single and two-seeded fruits in the feeding roller is troublesome due to the variation in shape.

6.3 Hammering mechanism

Link mechanism was used to imitate hammering action over tamarind fruit. 400 mm long and 25.4 mm diameter polished rod was mounted with lateral frame utilizing 25.4 mm diameter bearing block over the lateral frame. One end of the

Figure 9.
Tamarind deseeder developed at Tamil Nadu Agricultural University, Coimbatore.

Figure 10.
A hammer-type tamarind deseeder is available at Tamil Nadu Agricultural University.

polished rod was fitted with FPS 100 pump bearing which touches the round flange to transmit reciprocating motion. A mild steel flat of 40×12 mm was spring-loaded and mounted on the shaft within the space between the bearing block to imitate hammering action and the height of the flat was 300 mm. The top end of the flat was screwed with a wooden portion to imitate a wooden hammer (**Figure 10**) [8].

7. Value addition and by-products

7.1 Tamarind pulp

The most important and generally utilized part of the tamarind tree is its natural product pulp. It establishes 30–50% of the ripe fruit, the shell and fiber represent 11–30%, and the seed around 25–40% [9]. Pulp is rich in pectin and reducing sugars and contains critical measures of organic acids, 98% of which is tartaric acid. It is a unique plant acid that is generated from the principal carbohydrate products of photosynthesis and is not utilized metabolically by the plant once formed. The primary flavor compound of the pulp is 2-acetyl furan. The quantity of tartaric acid does not diminish as the fruit ripens, implying that it is stable, in the development of fruit. Reducing sugars grow to 30–40% during this stage of fruit development, giving the sour fruit a sweeter taste.

Tamarind pulp was assessed based on its physicochemical properties such as crude protein, crude fiber, fat, ash, moisture content, water activity (*A_w*), particle shape, particle size distribution, and density (Figure 11 and Table 2) [10].

Figure 11.
Tamarind fruit pulp.

S. no.	Proximate analysis (%)	Tamarind pulp +10% w/v maltodextrin
1.	Moisture content	5.15 ± 0.15
2.	Crude protein	0.43 ± 0.02
3.	Crude fiber	79.92 ± 0.85
4.	Ash	17.80 ± 2.59
5.	Fat	0.43 ± 0.18
6.	Water activity (<i>A_w</i>)	0.69 ± 0.01

Table 2.
Proximate analysis of tamarind pulp.

8. Processed products from tamarind pulp

8.1 Tamarind beverage

The tamarind fruit pulp is used for the preparation of beverages. It can be used to make high-quality ready-to-serve beverages, syrups, and concentrates with a six-month shelf life when stored at room temperature [11]. On a small scale, the fruit pulp is dissolved in water and squeezed by hand to make a delightful drink. Water is added to dilute the drink after the extraneous substance is removed. Tamarind pulp is a delightful drink in southern and central America, as well as Asia. Arnold [12]

Component	F1 (g)	F2 (g)	F3 (g)	F4 (g)
Tamarind pulp	100	120	80	80
Sugar	40	30	30	40
Purified water (mL)	500	500	500	500

Table 3.
Design of formulations to prepare the natural tamarind beverage.

Parameter	F1	F2	F3	F4
pH	2.73 ± 0.08	2.88 ± 0.02	2.84 ± 0.01	2.83 ± 0.01
TSS (Bx)	12.36 ± 0.39	10.83 ± 0.06	9.70 ± 0.10	10.73 ± 0.15

Table 4.
Results of pH and total solids of the natural beverage of tamarind before pasteurizing.

studied the physicochemical properties of natural tamarind beverages under four different formulations (**Tables 3 and 4**).

8.2 Tamarind syrup

Tamarind syrup is created by softening immature fruit pulp and straining it through a cheesecloth. The pulping process involves breaking the shells by hand and agitating the pulp and seeds in water to separate the pulp and seeds. A half-teaspoon of baking soda is poured into a cup of juice. The mixture is reduced to one-half of its original volume while also eliminating the scum that has risen to the surface. The juice is strained once more. A quarter cup of sugar is added to every cup collected. After 20 min, the mixture is boiled once more. The cooled syrup is poured into the container bottles that have been sterilized and sealed. The suggested tamarind pulp content in syrup is 20–24% to make a beverage with distinct flavor and acidity. This syrup comprises 56.7% total solids and 43.8% reducing sugar tartaric acid a total acidity of 1.11% as tartaric acid.

9. Tamarind juice concentrate

Tamarind concentrate is an acid pulp concentrate made from tamarind pulp that is free of skin, seed, fibers, and other impurities. The pulp from the tamarind pods is collected, and the juice is extracted from the pulp. The shells are broken by hand and agitated in water during the pulping process. The suggested tamarind pulp content in syrup is 20–24% to make a beverage with a distinct flavor and acidity [13]. By adding gelatine to clarified tamarind juice, the structural and colloidal phases are fully eliminated. The juice is translucent and retains its color and flavor. Under vacuum, insoluble particles are removed and soluble extracts are concentrated (**Figure 12**).

Deepika [14] studied Spray Drying of Tamarind Juice Concentrate and Powder Characteristics, the results are shown in **Table 5**.

9.1 Tamarind pulp powder

Tamarind pulp powder (TPP) is a convenience food manufactured from tamarind pulp that has been concentrated, dried, and milled into a powder. TPP is made

Figure 12.
Processing of tamarind juice concentrate.

Parameters		Mean value
Moisture content (wb)		30.13
Water activity, a_w		0.836
pH		1.63
Bulk density (g/cm ³)		0.905
Color	L	2.04
	a	1.78
	b	1.77
Tartaric acid (%)		13.07
Total sugars (%)		41.2
Protein (%)		2.1
Crude fiber (%)		2.0

Table 5.
Physicochemical properties of tamarind juice concentrate.

by concentrating, drying, and grinding tamarind pulp into a fine powder. In many Indian recipes and sauces, tamarind powder is used as a condiment/adjunct and souring ingredient. It has a large market potential as a convenient product.

9.2 Foam mat dried tamarind pulp powder

Liquid foods are whipped into stable foams and then air-dried using the foam mat drying process. Lower drying temperatures and faster drying times are the key benefits of foam-mat drying processes. The larger surface area exposed to the drying air, which speeds up the drying process, is responsible for these advantages.

The lack of foam stability throughout the heating cycle, however, should be taken into account. Cellular breakdown occurs when the foam does not remain stable, presenting major problems during the drying process. This drawback can be overcome by using a film stabilizer, such as polymeric material. Vernon-Carter et al.

[15] reported drying tamarind pulp using foam mat drying with various foaming agents. Mesquite gum, ovalbumin, and a low molecular weight surface active blend were hydrated to 50% (w/w) solutions and applied to the samples single or in combination (**Figure 13**).

9.3 Spray-dried tamarind juice concentrate (TJC) powder

See **Figure 14** and **Table 6**.

9.4 Drum drying of tamarind pulp

Weerachet et al. [16] studied the production of tamarind powder by drum dryer using Maltodextrin (MD) and Arabic gum (AG) as adjuncts (**Figures 15 and 16** and **Table 7**).

Figure 13.
Tamarind pulp powder.

Figure 14.
Flow chart for the preparation of spray-dried TJC powder.

S. no	Quality attributes	Spray-dried TJC powder			
		Storage period (days)			
		1	30	60	90
1.	Moisture content (w.b)	2.14	2.86	3.29	3.89
2.	Water activity, a_w	0.263	0.298	0.329	0.399
3.	Bulk density, g/cm ³	0.492	0.522	0.586	0.602
4.	Tartaric acid (%)	9.87	10.84	11.85	13.91
5.	Solubility (%)	88.3	83.21	78.75	72.83
6.	Wettability (s)	76	91	125	154
7.	Dispersibility (%)	80.16	74.65	69.00	62.34
8.	Color value				
	Redness ('a' value)	15.84	13.20	10.89	7.99
	Yellowness ('b' value)	24.07	22.15	21.32	19.56

Table 6.
Quality changes in spray-dried TJC powder during storage packed in Aluminum foil pouches [14].

Figure 15.
Schematic diagram of drum dryer.

9.5 Fruit leather

Fruit leather prepared from the dried sheets of tamarind fruit pulp will have a soft, rubbery texture and a sweet taste (**Figure 17**) [17]. Ghada et al. [18] studied the effect of different drying methods (cabinet drier (70°C) and solar drier (54 ± 4°C)) on the quality and consumer acceptability of tamarind leathers (**Figure 18**). Results showed that drying methods influence the color changes of tamarind leather. Effect of drying on quality characteristics are shown in **Table 8**.

9.6 Tamarind candy

Tamarind candy is one of the most liked products by consumers because of its natural sour-sweet blend. Candies are prepared after boiling tamarind pulp with a sufficient amount of sugar and cooking it with a very little amount of water. Arghya

Figure 16.
The processing flow chart for drum drying of tamarind pulp.

Drying condition				Bulk density (g/ml)	Moisture content (% wb)	Water activity	Solubility (second)
No.	Drying aid	Drying temperature (°C)	Ratio of tamarind juice and drying aid				
1	MD	120	1:1.4	0.816 ^a ± 0.066	3.46 ^a ± 0.03	0.260 ^a ± 0.003	83 ^{a,b} ± 2
2	MD	140	1:0.8	0.781 ^a ± 0.045	3.38 ^b ± 0.03	0.326 ^b ± 0.006	98 ^a ± 18
3	MD	140	1:1.4	0.478 ^b ± 0.063	3.11 ^c ± 0.04	0.342 ^c ± 0.001	8 ^c ± 1
4	AG	120	1:0.4	0.731 ^{a,c} ± 0.038	3.20 ^d ± 0.04	0.306 ^d ± 0.007	79 ^{a,b} ± 18
5	AG	120	1:0.8	0.790 ^a ± 0.037	3.62 ^c ± 0.04	0.265 ^{a,c} ± 0.006	73 ^b ± 8
6	AG	140	1:0.4	0.648 ^c ± 0.032	3.09 ^c ± 0.02	0.276 ^c ± 0.002	140 ^d ± 8
7	AG	140	1:0.8	0.783 ^a ± 0.094	3.41 ^{a,b} ± 0.03	0.263 ^a ± 0.012	16 ^c ± 2

Note: Bulk density, color, moisture content, water activity and solubility values are mean ± standard deviation (n = 3). Means with the same superscript within same column are insignificant different (P > 0.05).

Table 7.
Bulk density, moisture content, water activity, and solubility of tamarind powders.

Figure 17.
Process flow chart for developing tamarind fruit leather.

Figure 18.
Tamarind fruit leather.

Parameter	Cabinet drier	Solar drier	S.E	LSD (5%)
Texture	3.29 ± 0.31	2.52 ± 0.36	0.336	0.762
Color	0.138 ± 0.01	0.043 ± 0.03	0.010	0.022
Rehydration ratio	1.44 ± 0.16	1.78 ± 0.26	0.214	0.484
Drying ratio	3.50 ± 0.00	3.25 ± 0.06	0.039	0.088
pH-value	2.78 ± 0.03	2.81 ± 0.03	0.029	0.067
Titrateable acidity	6.86 ± 0.03	7.83 ± 0.39	0.274	0.622

Table 8.
Effect of different drying methods on quality characteristics of tamarind leathers.

Mani et al. [19] standardized the recipe for the preparation of Tamarind candy (Figures 19 and 20).

9.7 Tamarind pickle

To make tamarind pickle, the commercially available pulp is used. Pickles are hot, spicy, and salty-sour in flavor, and they can be stored for months. The inclusion of salt, enhanced acidity, and spices aid in preservation (Figures 21 and 22).

Figure 19.
Flow chart for tamarind candy preparation.

Figure 20.
Tamarind candy.

Figure 21.
Flow chart for tamarind pickle preparation.

Figure 22.
Tamarind pickle.

9.8 Tamarind ketchup

Clean the tamarind pulp, then boil it in freshwater to extract the tamarind puree. Cook on medium heat with 10% sugar and 1% salt. Then take it off the fire and combine it with the spices. Boil the edible oil in a saucepan and put sliced ginger, small bits of garlic, and chili along with the product and cool down the product before packing (**Figure 23**).

9.9 Champoy

Tamarind fruits can also be made into balls, or “champoy,” a popular tamarind snack in the Philippines. Two cups of boiled and mashed sweet potato, two cups of

Figure 23.
Tamarind ketchup.

sugar, a one-eighth cup of salt, and one cup of water are added to one cup of pulp with seeds. The mixture is heated over low heat, stirring constantly, until it thickens and can be molded into balls (**Figures 24 and 25**).

9.10 Tamarind ade

This is a delicious tamarind drink made in the Philippines and several tropical American countries by blending ripe pulp with sugar and water until it reaches the desired taste. Making Ade at home is as simple as shelling the fruits, placing them in 2–3 L of water, allowing it to stand for a brief time, then adding a tablespoon of sugar and vigorously shaking. Spices like cloves, cinnamon, ginger, pepper, or lime slices are sometimes added to increase the flavor [20].

Figure 24.
Tamarind balls.

Figure 25.
Tamarind Ade.

10. By-products of tamarind

10.1 Tamarind seed oil

Tamarind seed kernels produce an amber-colored oil that is odorless and sweet in flavor, similar to linseed oil. It is used in varnishes, paints, and lamp oil [2, 20], but it is also considered to be pleasant and of culinary quality [2, 20]. Tamarind oil has an iodine content of less than 100 mg/100 g, making it a non-drying oil (**Figure 26**).

10.2 Fruit shell

Tamarind shell is used as the carbon precursor for generating the activated carbon (AC) and the resultant AC materials utilized for water purification and supercapacitor applications. Vengatesan et al. [21] studied the tamarind shell-derived N-doped carbon for capacitive deionization (CDI) (**Figure 27**).

N-doping is proposed to be an effective method in not only improving the electrical conductivity and wettability of the carbon but also played a crucial role in

Figure 26.
Tamarind seed oil.

Figure 27.
Schematic representation of the formation of NTC-800.

enhancing the electro-sorption performance. As such, the low-cost biomass waste tamarind shell derived N-doped carbon nanosheets developed offer a promising electrode material for conventional high-performance symmetric CDI applications.

10.3 Bark

Tamarind barks and leaves contain a yellowish or brownish bitter-tasting organic substance called Tannin. The bark has 70% of tannin and found a great place for its usage in the tanning industry. Bark tannins are utilized in the production of ink and the fixation of colors in Zambia [2]. Many other African countries use the bark to manufacture ink. Tamarind twigs are used as “chewsticks,” while the bark is utilized as a “chewing gum” masticatory, either alone or as a lime replacement in betel nut [2]. Hordenine is an alkaloid found in the bark [20].

Lac: Tamarind tree is a host for lac insect that deposits a resin on the twigs. This product should be harvested and sold as a stick lac, but it is not considered an important source.

10.4 Tamarind seed gum

Tamarind gum is obtained from the endosperm of seeds of the tamarind tree, which is a seed gum with potential industrial applications [22]. Tamarind gum is having applications in paper, food, textile industry, etc. The composition of tamarind kernel, the source of gum, resembles the cereals. With 15.4% to 12.7% protein, 3–7.5% oil, 7–8.2% crude fiber, 61–72.2% non-fiber carbohydrates, 2.45–3.3% ash (d.b) [23].

11. Conclusion

Tamarind is a crop that can be eaten as a fruit or used as a condiment. The fruit has a delectable sour-sweet flavor. It’s full of vitamins and minerals, as well as antioxidants. Due to increased knowledge of Good Manufacturing Practices (GMP) and labor scarcity, mechanized tamarind processing without human intervention is expected [24]. To make tamarind processing easier, state agricultural universities developed and distributed machinery for the advantage of processors and to assure hygienic processing techniques. Tamarind can be used to produce many values added and by-products so that it fetches more market price to the producers. Physicochemical, thermal, structural changes take place during value addition of tamarind. Research in these areas is carried out to optimize changes in properties.

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