International Journal of Bio-resource and Stress Management
https://ojs.pphouse.org/index.php/IJBSM
Crossref
IJBSM November 2023, 14(11):1530-1538 Print ISSN 0976-3988 Online ISSN 0976-4038
Article AR4872a
Review Article
Natural Resource Management
DOI: HTTPS://DOI.ORG/10.23910/1.2023.4872a

Engineering Properties, Processing and Value Addition of Tamarind: A Review

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ABSTRACT

Tamarind is widely consumed as fruit and spices in India. Tamarind contains pulp, seeds, shell and fibres. The pulp, which makes up between 30 and 50% of the mature fruit, is rich in reducing sugars, pectin, protein, fiber, and cellulose substances. Study of various physical engineering properties such as moisture content, fruit size, length, width, thickness, and weight (pulp, seed, shell, etc.) is important for designing the post-harvest machineries of tamarind. Major unit operations for processing of tamarind includes drying, dehulling, deseeding, pressing and storage. Traditional and mechanical approaches are used for these operations. Mechanical approaches of tamarind processing are carried out by dehuller and deseeder machinery. One of the crucial unit procedures in the processing of tamarind is deseeding which can be done by deseeder, mechanically. Processing of raw tamarind into value-added goods may increase its worth in addition to increase in shelf life. Additionally, it boosts the income of producers and processors. Value added products of tamarind are pulp, tamarind juice concentrate, tamarind pulp powder, tamarind pickle, tamarind jam, tamarind syrup, tamarind candy, tamarind kernel powder, dried fruit block, tamarind chutney and beverages. Tamarind is also rich in major amino acids phytochemicals and hence it carries the properties of antidiabetic, antibacterial, antivenomic, antioxidant. This paper provides an overview of the engineering properties, processing technologies, value added products, technologies and machineries developed/available for tamarind and its health benefits which will further help in machinery, protocol, technology and product design and development.

KEYWORDS: Mechanization, physical properties, tamarind, value added product

Citation* (VANCOUVER)*: Bidyalakshmi et al., Engineering Properties, Processing and Value Addition of Tamarind: A review. *International Journal of Bio-resource and Stress Management,* 2023; 14(11), 1530-1538. HTTPS://DOI.ORG/10.23910/1.2023.4872a.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

RECEIVED on 03rd September 2023 RECEIVED in revised form on 27th October 2023 ACCEPTED in final form on 12th November 2023 PUBLISHED on 25th November 2023

1. INTRODUCTION

Tamarind (*Tamarindus indica* L.) (Hindi-*Imli*) belongs to dicotyledonous family Leguminosae and is native to tropical Africa and found in most of the tropical regions. At present it is well spread all across South Asia and also some regions of America and Australia (Anonymous, 2021). India ranks sixth in the export revenue of tamarind (Muzaffar and Kumar, 2017). Tamarind products from India are exported to approximately 60 different countries across the globe (Anonymous, 2022). It is mostly used for its fruit, which may be consumed either fresh or processed (Bagul et al., 2015). Due to its sour flavor and taste, tamarind pulp is utilized in a variety of recipes. The tamarind plant's root, body, fruit, and leaves all have significant nutritional value and medical applications, in addition to its industrial and economic significance (Kuru, 2014).

The tree mostly grows wild, although it is cultivated to a limited extent. It is particularly abundant in the Indian States of Madhya Pradesh, Bihar, Andhra Pradesh, Karnataka, Tamil Nadu, Chhattisgarh, Bihar, and West Bengal. Fruits are harvested when the pulp turns to rusty brown colour and contains 38% moisture. There are two varieties of tamarind in India: brown and red varieties. The red tamarind pulp has less acidic flavour on the other hand, the brown has a more acidic or sour flavour.

The tamarind fruit contains about 11% pod shell and fibre, 55% pulp, and 34% seeds (Figure 1). Fruit pulp has the most tartaric acid and is the main acidulant used in Indian and Asian cuisine. Despite its vast range of household and industrial uses, ease of cultivation, and lack of major pests and illnesses, tamarind remains as wild tree underutilized to meet expanding commercial requirements. The pulp is sun-dried or sugared and kept for months without losing quality. It is utilized in medicinal and culinary preparation. Traditional processing is commonly employed in food preparation, although its commercial uses (pasteurized juices, tamarind paste) are still developing. However, tamarind tree parts like leaves, pulp, fibre shell are mostly consumed directly but it is also being explored for extraction of essential compounds for further use as food, feed, fuel, pharmaceutical, textile, packaging industries etc. (Ghaffaripour et al., 2017; Israel and Murthy, 2019)

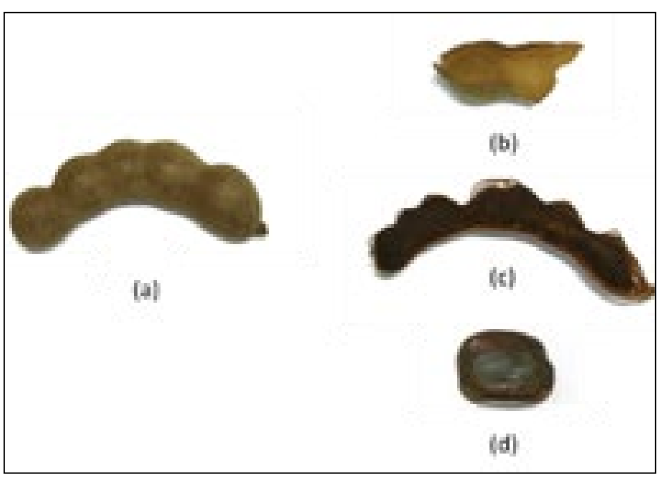

Figure 1: (a) Tamarind fruit: (b) shell, (c) pulp, and (d) seed

Engineering characteristics, such as the physical and frictional properties of the tamarind play a significant role in many issues relating to the design of a particular machine or study of the behaviour of the product in carrying out the crop production and post-harvest activities. (Viresh et al., 2016). Mahajani (2020) have also reported some physical parameters of whole tamarind seeds collected from Rajasthan, India. Various physical properties of tamarind seeds, as reported by different authors, are presented in Table 2.

The shelf life of tamarind fruit can be enhanced through processing. Various value-added products such as pulp, tamarind juice concentrate, tamarind pulp powder, tamarind pickle, tamarind jam, tamarind syrup, tamarind kernel powder (TKP) (Nath et al., 2022) can be prepared. India exports tamarind and its products to about 60 countries (Anonymous., 2022). TKP can be utilized to create biodegradable films for food packaging applications to limit the use of plastic-based materials, (Nath et al., 2022; Chowdhury et al., 2022). Panchal et al. (2014) and Zawawi et al. (2019) performed the oil analysis recovered from the tamarind seed, whereas a lot of work has been performed in developing the value added products and new formulation using tamarind products (Bagul et al., 2018; Uthai et al., 2020; Wu et al., 2020; Sultana et al., 2020). The post-harvest management includes gathering, drying, dehulling, deseeding, packing, and storing. These operations are crucial in preserving the quality and increasing the shelf life of pulp and its products. This review article provides the insight details of the tamarind properties in terms of engineering properties, different processing techniques, machinery involved and various value added products (Sreedevi et al., 2022).

2. ENGINEERING PROPERTIES OF TAMARIND

The physical properties such as length, breadth, thickness, and mass of the fruit of tamarind reported by various authors are listed in Table 1. Table no. 2 provides the gravimetric properties viz. geometric mean diameter, sphericity index, bulk density, true density, porosity, and of tamarind.

3. PROCESSING OF TAMARIND

Tamarind processing is a multi-step processes that involves cleaning, hulling, shelling, and drying the

Table 1: Physical properties of tamarind

Tamarind types	Tamarind fruit			Tamarind pulp (with seed)			Wt. of single fruit (g)	No. of seeds/ fruit	References
	Length (mm)	Breadth (mm)	Thickness (mm)	Length (mm)	Breadth (mm)	Thickness (mm)			
NFN-6	89.86	19.38	14.28	87.41	16.65	11.26	14.77	5.24	Sreedevi et al., 2022
Sweet tamarind	92.00	20.06	14.01	90.28	17.95	10.78	15.04	5.56	
Red tamarind	97.44	19.13	17.33	93.66	16.90	16.05	19.72	6.36	
SMG-14	105.52	18.30	12.18	103.42	16.36	10.32	11.24	7.65	
NFN-7	110.00	21.31	18.64	98.92	18.18	15.43	14.94	7.24	
DTS-2	115.70	30.23	18.16	113.14	28.18	16.19	24.86	5.93	
PKM-1	100.28	24.38	16.33	98.83	22.68	13.34	15.60	6.18	
Tamarind (22% m.c.)	112.0	20.0	12.0						Sinha et al., 2012
17.90 % m.c	112.0	20.0	11.0						
15.80 % m.c.	111.0	19.0	10.0						
Unripe whole tamarind fruit	101.27± 43.27	21.68± 3.81	15.68± 3.57				25.70± 18.93	6.36± 2.92	Sreedevi et.al., 2020
Ripe whole tama-rind fruit	53.46± 19.84	20.18± 2.77	13.71± 2.16				5.47± 2.48	5.32± 2.85	
Ripe tamarind fruit (without husk and with seed)	71.74± 32.05	15.52 ± 2.61	9.40± 1.76						

fruit. This process is necessary in order to produce tamarind pulp and other variety of food products such as sauces, curries, chutneys, jams, candy, juice concentrate etc. It can be processed using both dry and wet processing methods.

The first step in tamarind processing is to clean the fruit. This is typically done by soaking the fruit in water and then brushing it off with a brush or cloth. The fruit should then be rinsed off with water to remove any dirt or debris. The next step is to hull the fruit, which involves removing the hard outer shell. This can be done by hand or with a machine (huller/sheller). Once the hull is removed, the fruit is then shelled. This involves removing the seeds from the pulp (deseeder). The final step is to dry the tamarind pulp through sun drying or by using mechanical dryer. The dried pulp can then be used in various food products. For the sale as cake, deseeded and dried tamarind then processed to remove fibers (defibering) which are then pressed to form tamarind cake. These cakes are packed to sale in the market or can be further used for processing (Sudha. et al, 2022).

The by-products generated from tamarind processing includes tamarind seed, fibre, and outer shell, where the major by-product is tamarind seed. Tamarind seeds are of high economic value as its kernels are used for extracting tamarind oil and for use in other medicinal purpose.

3.1. Mechanization

The machinery/equipment required for post-harvest operations of tamarind are listed in Table no. 3.

4. VALUE-ADDED PRODUCTS

4.1. Tamarind pulp

Tamarind is valued mostly for its fruit pulp, which are used for a wide variety of domestic and industrial purposes. The pulp contains reducing sugars, pectin, protein, fibre, and cellulosic materials and accounts for 30–50% of the ripe fruit. Tamarind pulp is high in amino acids but low in protein and oil. It is rich in minerals (calcium, phosphorus, copper, and manganese), and vitamin B is the most abundant among vitamins (Muzaffar and Kumar, 2017). The percentages of the constituent components vary by sample, with tartaric acid ranging from 8 to 18%, reducing sugars 25 to 45%, pectin 2–3.5%, and protein 2–3% respectively (Ferrara, 2019; Muzaffar and Kumar, 2015). The pulp has an acidic taste due to the tartaric acid content (Obulesu and Bhattacharya, 2011). Table no 4 shows the composition of tamarind pulp (Table 4).

In India, the pulp is eaten raw and sweetened with sugar. The pulp is usually removed from the pod and used to

Table 2: Gravimetric properties of different tamarind fruit genotypes

Tamarind genotypes	Geometric mean diameter (mm)	Sphericity index	Surface area (mm^2)	Bulk density (kg m^{-3})	True density (kg m^{-3})	Porosity (%)	Angle of repose (°)	References
NFN-6	26.63± 14.86	0.28± 0.06		335.00± 10.58	676.11± 91.99	49.83± 7.03		Sreedevi et.al., 2022
Sweet tamarind	28.17± 16.96	0.29± 0.07		350.00± 20.03	614.10± 25.18	42.81± 5.43		
Red tamarind	35.14± 22.68	0.34± 0.09		362.00± 18.19	491.36± 28.06	26.31± 0.68		
SMG-14	24.57± 10.30	0.23± 0.05		236.00± 11.53	656.67± 55.08	63.90± 3.40		
NFN-7	45.00± 17.12	0.40± 0.08		263.67± 12.06	693.89± 63.47	61.86± 2.51		
DTS-2	66.17± 32.95	0.55± 0.12		318.00± 28.00	683.07± 97.93	52.39± 11.33		
PKM-1	41.61± 18.03	0.40± 0.08		313.33± 20.33	532.41± 36.68	41.13± 0.67		
Whole Tamarind fruit with hull and seed	33.87	0.33		404.66± 5.68	785.23± 36.48	48.37± 2.91		Sreedevi et.al., 2020
Tamarind fruit without hull and with seed	10.68± 5.31	0.15± 0.03		714.00± 45.21	1077.40± 58.37	33.68± 3.54		
Tamarind fruit without hull and seed (pulp)	0.84± 0.67	0.01± 0.01		116.08± 0.98	166.45± 18.8	29.61± 8.63		
Whole Tamarind fruit with hull and seed			3000.18	240.39	469.59	48.80	35.4	Sudha. et al, 2022
Tamarind fruit without hull and with seed	26.21	0.28	1904.98	612.24	1182.41	48.22	39.4	

prepare juice, jam, syrup and candy. Manual extraction of pulp from tamarind fruit begins with deshelling the fruit, which is then soaked in water for a period of time before the pulp is extracted.

For tamarind pulp extraction, tamarind pulp is separated from the outer shell and soaked in 1:2.5 (1:2) water for 33 minutes at 39°C (Muzaffar and Kumar, 2016). The mixture was thoroughly mixed and sieved to separate the fibres and seeds from the pulp. The mixture was then filtered through muslin cloth, yielding a fine pulp. To extract the water solubles, the tamarind pulp was boiled in water and concentrated to 65–70% (Rao and Mathew, 2012). Tartaric acid 13%, inverted sugars 50%, pectin 2%, protein 3%, cellulosic material 2%, and moisture 30% were reported to be the approximate composition of tamarind pulp extract. The pulp juice extract and dried powdered pulp are widely used as preservatives in the food industry.

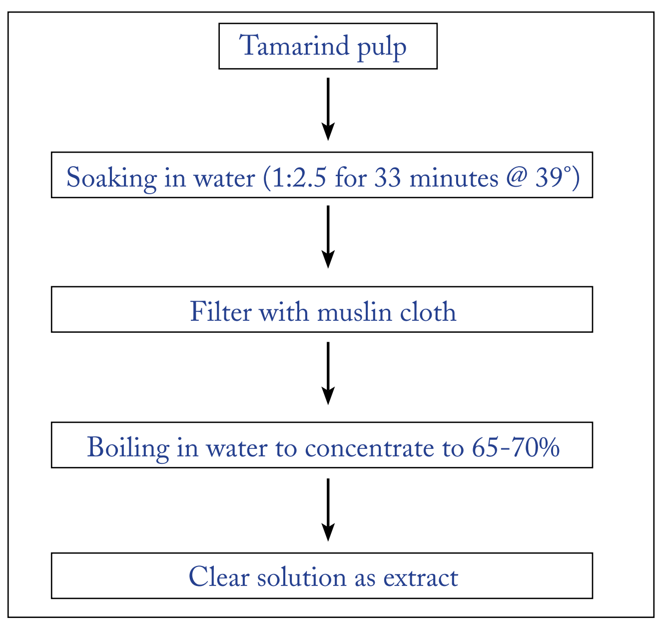

Figure 2: Process for tamarind pulp extract from tamarind pulp

4.2. Tamarind juice concentrate (TJC)

After soaking ripe fruits in water and removing fibrous

Table 3: Machineries for tamarind post-harvest operations

Sl. No.	Item	Description	Reference
1.	Tamarind dehuller	• Developed by Tamil Nadu Agricultural University (TNAU), Coimbatore, India • Capacity: 100 kg h^{-1} capacity and dehulling efficiency: 94% • Principle: Impact force and sieve shaking mechanism. The dried tamarind fruit supplied via the feed hopper was struck by the spinning beaters' impact force. • Output: Dehulled, unhulled, and hulled fruits	Sudha et al., 2022
2.	Tamarind deseeder	• Developed by Tamil Nadu Agricultural University (TNAU), Coimbatore, India • Impact-and-shear tamarind deseeder • Commonly utilised in Krishnagiri and Dharmapuri areas to deseed tiny tamarinds. • Costs Rs. 20,000 and deseeds 83%	
3.		• Hammer-type tamarind deseeder developed at Kumulur, Tamil Nadu Agricultural University • Features: feeding roller with rubber lining, hammering mechanism, motor, power transmission framework and casing • The machine works at 5 rpm (0.06 m/s) to deseed tamarind at 22.5% moisture content on a dry basis with little mechanical damage to seed (0.3%) and pulp (14.94%)	
4.	Impact and shear type tamarind deseeder	• Developed by Department of Food and Agricultural Process Engineering, TNAU, Coimbatore • Principle: applying impact force and simultaneous shear by studs mounted rotor assembly encased with sieve • The peripheral speed of 1.3 m/s enclosed with the cylindrical sieve constructed of oblong sheet at 23.5% moisture yielded the highest deseeding effectiveness. • Capacity: 60 kg h^{-1}	Pandian et al., 2017

Table 4: Composition of tamarind pulp

Minerals and nutrients	Quantity (mg 100 g^{-1})	Reference
Ca	117.1	(Okello et al., 2017; Okello et al., 2018).
Mg	84.7	
Na	80.8	
K	20.9	
Fe	15.6	
P	13.8	
Zn	3.3	
Vitamin C	201.70±0.02	
Β-Carotenoids	0.16±0.02	

debris, the fruits are squeezed to create fruit juice concentrate. It is a thick juice with a built-in preservative.

Tamarind juice concentrate (TJC) is made by boiling pulp. Extracting fresh pulp requires dilute extracts which yields 20% soluble solids extract. The pulp is then sieved and concentrated under vacuum until the soluble solids reach 68%. After chilling, the substance sets into jam-like consistency in sterilised glass containers (Singh et al., 2007).

4.3. Tamarind pulp powder (TPP)

Concentrating, drying, and grinding tamarind pulp produces TPP. Physico-chemical characteristics vary widely depending on production procedure. The nutritional values of tamarind pulp powder are 18.6–25% total solids and 8.7–11.1% tartaric acid, with an average of 3.5–8.8% moisture. The minerals had high calcium and potassium levels of 74 to 143 mg and 23.8 to 27.7 mg, respectively. Tamarind pulp powder is 20–41% starch (Singh et al., 2007).

Tamarind pulp powder can also be prepared using spray drying process. In this method, the maltodextrin, as a carrier, is mixed with tamarind pulp extract. The good quality powder on the basis of physical and structural properties can be obtained at inlet temperature of 155°C, outlet temperature of 100°C with tamarind pulp extract-maltodextrin ratio of 70:30 (Cynthia et al., 2015). Drum drying, foam mat drying, spray drying are also used for preparation of tamarind pulp powder (Sudha et al., 2022)

4.4. Tamarind pickle

Fresh tamarind fruits are chosen, soaked in clean water for 12 hours, and the pulp is separated from the tamarind before being used to make pickles. Tamarind pickle is made from ripened fruit without shells, fibres, or seeds. Spices and salt are the major component for making tamarind pickle. The pickles can store and used up to 1–1.2 years. The taste of the pickle can be made hot, spicy, sour and sweet. Figure 3. Shows the procedure for making the tamarind pickle (Mani et al., 2020). The spice mixture per kg of tamarind are: Cloves (3–4 no.), black cumin (30 g), cumin seed (50 g), coriander (40 g), cinnamon (1–2 g), cardamom (2 g), chillies (10–12 no.), salt (30 g), mustard oil (250 ml) and black pepper (30 g).

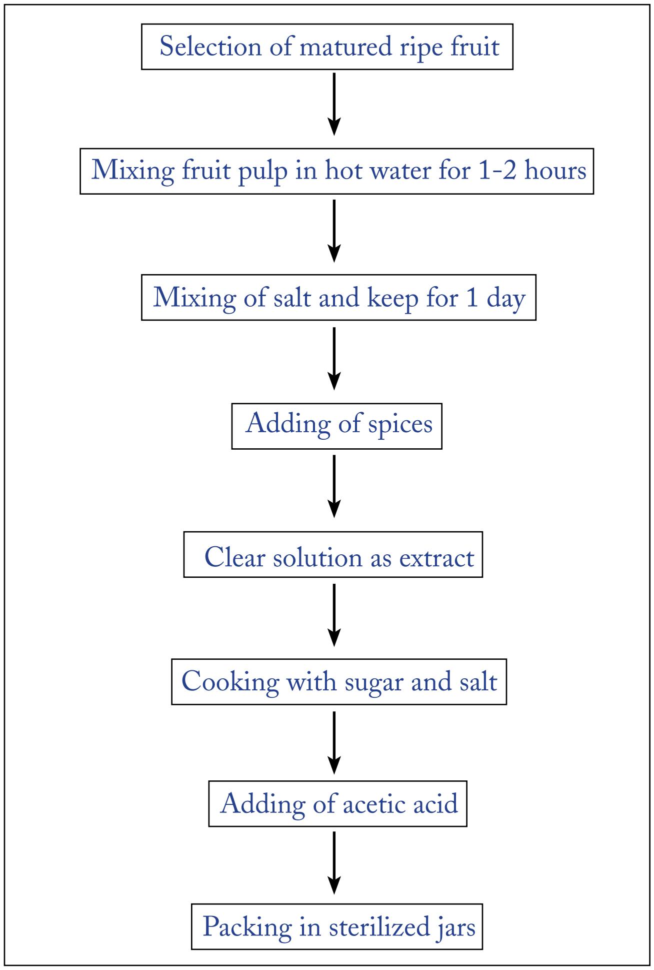

Figure 3: Flowchart for making tamarind candy

4.5. Tamarind jam

Tamarind jam is made by shelling the ripe fruit and boiling at 100°C for 10 minutes. The pulp and seed is then separated by draining. Two cups of brown sugar are added for each cup of pulp, and the mixture is heated and stirred while boiling until thick. The sugar is added to maintain the proper balance of sugar, acid, and pectin. The tamarind jam has a shelf life of nine to twelve months. (Mani et al., 2020).

4.6. Tamarind syrup

Tamarind syrup is made by boiling immature fruit pulp and straining it through cheesecloth. Each juice cup is mixed with half-teaspoon of baking soda and boil the mixture to half its volume. The developed scum is removed and filtered again. For each cup of the solution 1/4 cup of sugar is added and the mixture is boiled again for 20 minutes. The syrup is then cooled and packaged in sterile bottles (Singh et al., 2007).

4.7. Tamarind candy

Sweetened tamarind fruit or tamarind candy is made by peeling and covering ripe tamarinds in boiling (62°C) sugar syrup. Boiling syrup consists of three parts sugar and one part water. After three days, the fruits are removed from the syrup and re-covered with new syrup. The process is repeated until fruits are sweet. Sweetened fruits are kept on bamboo racks covered with a wire screen to keep flies out and allowed for sun drying. Dry fruits are packed and stored in cool and dry place for selling and consumption (Singh et al., 2007).

5. HEALTH BENEFITS OF TAMARIND

Tamarind is well regarded for its nutritious and excellent health-promoting qualities and is a significant source of nutrients and therapeutic properties. *Tamarindus indica* is thought to have significant antioxidant activity because to the widespread dispersion of polyphenol and flavonoid components. Phenolic chemicals of tamarind have specialised functions in antibacterial and anticancer actions as well as being advantageous for cardiovascular and immunological health. Whereas the flavonoids found in various tamarind sections have been shown to have anti-inflammatory, anti-diabetic, and antihyperlipidemic properties that can be used to address a variety of risks to human health.

Tamarind is said to have antidiabetic, antibacterial, antivenomic, antioxidant, antimalarial, antimicrobial, antiparasitic, antifungal, antiviral, antinematodal features, cardioprotective, hepatoprotective, antiasthmatic, laxative, and anti-hyperlipidemic action since it is a rich source of the major important amino acids and phytochemicals (Nwodo, et al., 2011; Kuru, 2014; Indira Devi et al., 2019). Due to its low cost and accessibility, it can also be recommended as a nutritional supplement for patients who are undernourished. Tamarind offers curative properties for a variety of illnesses as (Kuru, 2014):

- Improves function of nervous system and immune system
- Diabetes management
- Check cholestrol level
- Beneficial for patient with piles and jaundice
- Helps in purifying blood
- Improves hair by preventing loss
- Good for skin health

• Helps weight management of body weight

Apart from the health benefits tamarind seeds does also contain some anti-nutritional factors like phytic acid, trypsin inhibitors, cyanogens etc. However, the levels of phytic acid is low compared to other sources like legumes. Phytic acid forms phytate-mineral-protein complexes and phytateprotein that inhibits the absorption of certain minerals, also interfere with the utilization of proteins and prevents the activity of digestive enzymes (Siddhuraju et al., 1995). Nevertheless, processing activities (soaking, autoclaving etc) are effective against phytate by eliminating it. The concentration of cyanogens in tamarind seeds is very low to have any negative effect (2.8 mg 100 g^{-1}). Moreover, cooking significantly improves the nutritional availability by eliminating cyanogens and reducing the the trypsin inhibitor activity by >98%.

Table 5: Other value added products

Sl. No.	Products	Description	Reference
1.	Tamarind kernel powder (TKP)	Tamarind kernel powder is obtained by crushing the tamarind seed. The paste prepared by boiling with water acts as good adhesive. The defatted TKP has a long shelf life and doesn't spoil when exposed to air. Can be used as thickening agent, ingredients into sauce and chutney preparation etc	Mani et al. (2020)
2.	Dried fruit block	The convenience required for tamarind export and long-distance transport is met by producing large-sized tamarind fruit bars or blocks. Tamarind pulp that has been seeded or deseeded is dried and compressed for commercial delivery to far-off locations. In remote locations, the resulting fruit block is typically sold by kilogram or per quintal rate.	
3.	Tamarind chutney	The green, immature fruits are used to make tamarind chutney, which is a type of condiment that undergoes minimal processing before being consumed. The fruits contain enough amounts of nutrients and have a high antioxidant content. Tamarind chutney is often prepared in a pan with a variety of spices and salts, and it is eaten alongside southern Indian foods such as idly and dosha.	
4.	Tamarind beverages	Tamarind beverage is the tamarind fruit concentrated in diluted form. For preparation of beverages, approximately 1.0 litre of water is combined with 1.5 to 2.0 g of tamarind pulp after the pulp has been removed from the seeds, fibres, and shell. Pepper, ginger, and clove are used as seasonings. Sugar is also added in small quantities as per the taste. The mixture is well mixed and then strained through a muslin cloth. After being pasteurized at 95°C for 8–10 minutes, the beverages can be kept for up to 2-3 months in sterilised bottles.	

6. CONCLUSION

Tamarind is widely consumed in India as fruit and spices. Study of the engineering properties is of paramount importance for designing the harvest and post-harvest equipment. This article listed machineries for post-harvest operations and value-added products that can be prepared from tamarind along with the process of preparation. This review will provide meaningful information on post-harvest management and processing of tamarind to the processors, researchers, entrepreneur and other stake holders who like to work on tamarind.

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