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Bacterial acrylamidase

Medicinal Properties of Tamarind Seeds: A Mini Review

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ABSTRACT

Tamarind seeds, scientifically known as *Tamarindus indica* L., has been found to possess notable antimicrobial effects making them a potential source for combating microbial infections. The unique phytochemical composition of tamarind seeds contributes to their antimicrobial activity. These compounds effectively inhibit the growth of various pathogenic bacteria and fungi, highlighting their potential in combating antimicrobial resistance. This review explores how tamarind seeds could serve as a new ingredient with medicinal properties.

INTRODUCTION

The World Health Organization (WHO) classifies plants with therapeutic properties as medicinal. WHO estimates that only about 15% of the approximately 300,000 plant species worldwide have been identified as having medicinal benefits. In developing countries, the use of medicinal plants remains widespread, with over 80% of the global population relying on traditional plant-based remedies for their primary healthcare needs [1]. More than 8,000 species of medicinal plants have been documented in Peninsular Malaysia, Sabah, and Sarawak. [2,3]. Tamarind is an ancient herbal plant first documented in traditional Sanskrit literature [4]. It is a commercially valuable plant found in Asia, Africa, and America. In Malaysia and Java, it is referred to as "Asam Jawa," while in other countries, it is known as 'Sampalok' in the Philippines, 'Magyee' in Myanmar, 'Ampul' in Cambodia, 'Makham' in Thailand, 'Suan Jiau' in China, and 'Indian date' in India [5]. Tamarind species exhibit distinct variations that can be classified as either sweet or sour. Sour varieties are common in most regions and thrive in warm climates, while sweet varieties are less common. In Thailand, farmers widely plant both sweet and sour tamarind types. However, Brazil rarely grows the sweet variety. Despite this, the Bebedouro farm in Sento Sé, Bahia, has successfully grown "sweet" tamarind, which has lower acidity than typical tamarinds. The scientific literature underrepresents the sweet variety of Tamarindus indica, with only a few published studies available to date [6].

The Benefits of Tamarind

Tamarind holds significant medicinal value and is widely used in Asia, Africa, and the Americas. Indian Ayurvedic and traditional African medicine incorporate various parts of the tamarind plant, including leaves, fruits, and seeds, into their treatments. Ancient Sanskrit literature documents the therapeutic properties of tamarind [7]. Tamarind fruits gained recognition for their therapeutic properties in Europe after Arab traders brought them from India [8].

In Africa, tamarind is employed in the treatment of numerous conditions, such as chest pain, colds, colic, conjunctivitis, constipation, diabetes, diarrhea, dry eyes, dysentery, gingivitis, hemorrhoids, indigestion, jaundice, keratitis, and leprosy [7]. Additionally, tamarind is traditionally

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used in Thai medicine as a blood tonic, expectorant, laxative, and digestive aid [8].

Tamarind has been used to treat various illnesses, including sunstroke symptoms, Datura toxicity, and the adverse effects of alcohol and cannabis use [9]. Tamarind is applied to wounds, a remedy for sore throats, and helps paralyzed individuals regain sensation. There is a common belief that tamarind has healing properties for malarial fever.

In Mauritius, tamarind pulp serves as a topical remedy for rheumatism, whereas in Southeast Asia, tamarind is used to address symptoms of chaulmoogra toxicity, which can occur from excessive use of this leprosy medication [10]. Moreover, a study explores the potential anti-diabetic properties of fermented and raw tamarind, highlighting how fermentation affects their antioxidant properties, phenolic content, amino acids, and mineral compositions. The research indicates that, while raw seeds contain higher levels of certain antioxidants, fermentation enhances the levels of essential vitamins and amino acids, potentially boosting their therapeutic effects. The findings suggest that fermented tamarind seeds, rich in bioactive compounds that inhibit enzymes involved in carbohydrate digestion, could play a valuable role in diabetes management by increasing antioxidant capacity and possibly improving insulin sensitivity [11].

In a different study, researchers evaluated how different solvents affected the extraction of antioxidant polyphenols from tamarind leaves and their ability to inhibit aldose reductase *in vitro*. They found that the extract obtained with distilled water contained the highest levels of phenolic and flavonoid compounds, demonstrated the strongest antioxidant activities, and showed the most significant inhibition of aldose reductase. Meanwhile, the highest FRAP value was observed in the aqueous methanol extract. Additionally, the polyphenol content showed a positive relationship with antioxidant activity and aldose reductase inhibition. These findings suggest that distilled water is the most effective solvent for extracting beneficial compounds from tamarind leaves, which could be used as nutraceuticals to help mitigate diabetic complications [12]. There is an increasing amount of research on the shift of tamarind from being a home remedy to its use in modern medicine, which will be discussed further in this review.

Biochemical Properties of Tamarind Seeds

Tamarind contains approximately 55% pulp, 34% seeds, and 11% shell. The seeds are made up of a 20–30% seed coat, or testa, and a 70–75% kernel, or endosperm [13]. Despite being brittle and tasteless, the seeds contain a variety of amino acids, flavonoids, polyphenols, and other biological components that have antimicrobial, antioxidant, and potential pharmaceutical properties.

The tamarind plant is highly useful, as every part of it has medicinal properties. For instance, the tamarind fruit aids digestion due to its laxative properties. The seeds are reported to have parasiticidal, anti-diarrheal, and nausea-inducing properties. Additionally, the shell has been found as beneficial for promoting epidermal wound healing [14], and extracts of the shell in ethyl acetate and ethanol demonstrate antioxidant activity.

Numerous studies have been conducted on tamarind seeds, with a particular focus on their biochemical and pharmacological qualities. Research has demonstrated that tamarind seed oil contains both polysaccharides and fatty acids. At least 32 fatty acids are found in tamarind seed oil, including 21 saturated and 11 unsaturated acids [15]. These fatty acids exhibit broad microbial resistance against most types of microorganisms. Furthermore, long-chain unsaturated fatty acids inhibit bacterial enoyl-acyl carrier protein reductase (FabI) and exhibit antibacterial activity. Particularly, linoleic acid, a type of unsaturated fatty acid, is an effective inhibitor of gram-positive bacteria [16].

Approximately 65% of tamarind seeds are made up of tamarind seed polysaccharides (TSP), which are chemically composed of glucose, xylose, and galactose in a 2.80:2.25:1.00 ratio [17,18]. TSP exhibits various biological activities, such as anti-inflammatory and antioxidant effects, and modulates the gut microbiota. These properties make TSP a potential candidate for treating conditions like colitis, dysentery, and diarrhoea [19]. TSP has garnered significant attention in the pharmaceutical industry as a mucoadhesive polymer. Mucoadhesion refers to the adhesion between a mucosal surface and another material [20].

A study by Gosh explored the use of tamarind seed polysaccharides (TSP) as a modified carrier for aspirin in tablet formulations [21]. Researchers also enhanced the intraocular absorption and therapeutic effectiveness of rufloxacin in the treatment of bacterial keratitis in rabbits using TSP-based mucoadhesive polymers [22]. This method potentially reduces corneal toxicity and improves patient treatment by minimizing drug administration. Additionally, TSP can be used to create microspheres and nanofiber-based bio-scaffolds for drug delivery and tissue engineering. TSP's versatile applications as a polymer in healthcare include innovative bioadhesive and extended-release drug carriers.

Antioxidant Properties of Tamarind Seeds

Tamarind seeds are a rich source of phenolic antioxidants, such as 2-hydroxy-3',4'-dihydroxy acetophenone, methyl 3,4-dihydroxybenzoate, 3,4-dihydroxy phenyl acetate, and epicatechin [23]. Raw and dry-heated seed coats of tamarind contain powerful antioxidant substances [24]. In a quantitative analysis using high-performance liquid chromatography revealed that the total phenolic compounds yield were 6.54 g/kg (dry weight) in the seeds and 2.82 g/kg (dry weight) in the pericarp [25].

Tamarind seed extract (TSE) has demonstrated as an effective antioxidant during activity against hydroxyl radicals, superoxide anions and peroxyl radicals [26]. TSE also prevented the formation of nitrite and NO, both *in vitro* and *in vivo*. Additionally, a cytotoxicity test on mouse peritoneal macrophages showed that TSE did not impact cell viability, leading to the conclusion that it is non-cytotoxic [8]. Research by Garg *et al.* identified substantial antioxidant properties in tamarind seed extract, which could be employed to prevent or suppress melanogenesis [27].

Given the association between oxidative stress, damage, and inflammation, the antioxidant potential of tamarind extracts was explored. The DPPH assay was used to generate a stable radical and assess radical scavenging capacity. The analysis demonstrated that both peel samples and seed extracts from chloroform and ethyl acetate exhibit significant antioxidant. Notably, the chloroform and ethyl acetate seed extracts exhibited higher antioxidant compared to the peel extracts. Plant-derived compounds have the advantage of being non-toxic compared to chemically synthesized alternatives. Phytochemical analysis conducted by Tavanappanavar *et al.* further highlighted various bioactivities, including antibacterial and antioxidant properties,

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reinforcing the therapeutic potential of tamarind peel and seeds [28]. The supercritical extracts contained the following fatty acids: 9,12-octadecadienoic acid (linoleic acid), cis-10-heptadecenoic acid, and n-hexadecanoic acid (palmitic acid). Researchers have explored monounsaturated fats, including oleic and linoleic acids, as natural antioxidants and consider it as promising alternatives to synthetic antioxidants, especially for food preservation. These findings align with the research by Luzia and Jorge, which demonstrated that tamarind extracts containing linoleic, stearic, oleic, and palmitic acids are effective in reducing low-density lipoprotein (LDL) levels [6]. This data may be valuable for the cosmetics and healthcare sectors [27]. These findings suggest the potential of tamarind seed extract for use as a health supplement and for therapeutic purposes.

Antimicrobial Properties of Tamarind Seeds

Most plant-derived bioactive compounds that are important in pharmaceuticals are secondary metabolites. The potency and concentration of these compounds produced as byproducts can significantly influence antimicrobial activities against certain microbial strains [30,31]. These compounds also could improve the medicinal use of current antibiotics by amplifying their effectiveness and preventing bacterial resistance [32,33]. Antimicrobial phytochemicals can be categorized according to the chemical structures, chemical composition, biosynthetic pathways, or solubility, as shown in **Table 1** [34].

Table 1. Medical plant phytochemical compounds and their antimicrobial properties.

Class	Subclass	Mechanism
Phenolics	Simple phenols	Substrate deprivation
	Phenolic acids	Membrane disruption
	Flavonoids	Bind to adhesins
	Flavones	Complex with cell wall
		Inactivate enzyme
	Tannins	Bind to proteins
		Bind to adhesins
		Enzyme inhibition
		Substrate deprivation
		Complex with cell wall
		Membrane disruption
		Metal ion complexation
Terpenoids, essential oils		Membrane disruption
Alkaloids		Intercalate into cell wall and/or DNA
Lectins and polypeptides		Block viral fusion or adsorption Form disulfide bridges

Researchers have extensively documented the broad-spectrum antimicrobial properties of *Tamarindus indica* extracts. These findings highlight how tamarind-derived compounds show promise as organic alternatives to fight various bacterial pathogens. Phenolics and terpenoids present in tamarind seeds, leaves, and fruit extracts contribute to their antimicrobial properties [35,36]. Scientists classify flavonoids as low molecular-weight polyphenolic phytochemicals that plants commonly produce [37]. They are excreted as secondary metabolites and are known to have various biological roles, including defence against microbial infections. In addition to their role in plants, *in vitro* studies have shown that flavonoids possess numerous pharmacological properties in humans, including antibacterial, free radical scavenging, hepatoprotective, anti-inflammatory, and anticancer effects [38]. Ethanol and methanol extracts of tamarind seeds contain flavonoids [35], and these extracts have demonstrated significant antimicrobial effects, particularly against *Klebsiella* sp., *E. coli*, *Staphylococcus*, and *Pseudomonas* sp. [35,36].

Tamarind seed extracts have been found to contain various fatty acids, such as palmitic acid, linoleic acid, and oleic acid. Fatty acids generally have a broad range of effects on different types of microorganisms, including bacteria, mycobacteria, filamentous fungi, yeast, enveloped viruses, and eukaryotic algae [37]. They can compromise cell membrane integrity in various ways, potentially causing cell lysis or the loss of essential cellular components [3,38]. Fatty acids also can disrupt nutrient uptake and energy production by interfering with electron transport and oxidative phosphorylation in the bacterial and mitochondrial membranes of eukaryotic microorganisms. In addition to disrupting membranes, fatty acids can interact with various intracellular targets and enzymes, including those involved in fatty acid synthesis [13,38]. Researchers have reported that long-chain unsaturated fatty acids, such as linoleic acid, inhibit bacterial enoyl-acyl carrier protein reductase (FabI), a key component of bacterial fatty acid production and a promising target for antibacterial agents [14].

In addition to their direct antimicrobial effects, fatty acids can also destroy bacteria through indirect mechanisms by limiting a microbe's ability to colonize or exploit a host or surface [15]. Biofilm, which is a significant contributor to illnesses and infections, provides an environment for microbial cells to thrive on various surfaces. Biofilm-forming bacteria are associated with over 80% of human surgical site infections, including prolonged wound infections [16]. Standard antibiotics face extreme challenges in treating biofilm-associated SSIs, often caused by multidrug-resistant bacteria in polymicrobial communities. Free fatty acids have the potential to inhibit biofilm development by disrupting adhesion and limiting communication between microbial cells [17].

Resistance to fatty acids is anticipated to be rare because these acids have diverse biological targets. Additionally, fatty acids can synergize with other antibacterial substances such as lysozyme, surfactants, and antimicrobial peptides (AMPs), as well as traditional antibiotics [18]. Synergistic combinations require less of each component to achieve the same antibacterial action, potentially reducing the adverse side effects of hazardous antibiotics. Furthermore, combining several agents can decrease the likelihood of bacteria acquiring drug resistance since they target different biological processes. For bacteria to thrive, they must simultaneously resist both components [20]. Combining other antimicrobial agents with free fatty acids may help address the increasing problem of microbial drug resistance.

Moreover, research is exploring the antibacterial potential of a trypsin inhibitor (TTI) extracted from tamarind seeds. The focus is on studying its genotoxicity and interactions with bacterial membranes through in-silico analysis. The study suggests that TTI is non-genotoxic at concentrations of 0.3 and 0.6 mg/mL. Additionally, molecular dynamics simulations indicate that TTI has a stronger affinity for gram-positive bacterial membranes compared to gram-negative ones. Notably, a peptide derived from TTI, called Peptidotrychyme59, shows significant antibacterial activity, especially against gram-positive bacteria. These findings suggest that TTI and its peptides could be promising candidates for developing new antibacterial agents, offering a potential solution to the growing challenge of antibiotic resistance [39].

Furthermore, researchers investigated the antimicrobial activity of tamarind extracts from the semi-arid regions of eastern Kenya. They aimed to highlight the plant's availability, affordability, and eco-friendliness for controlling pests and diseases. The study involved sequentially extracting tamarind leaves and fruits using methanol and water. They then tested the extracted samples against various pathogenic bacteria, including *Bacillus subtilis*, *Staphylococcus aureus*, *Pseudomonas aeruginosa, and Escherichia coli*. They discovered that the antimicrobial effects of tamarind extracts varied. They observed strong inhibition against *B. subtilis* and *P. aeruginosa*, while the extracts were ineffective against *S. aureus* and *E. coli*. Additionally, they found that both the extraction solvent and the region where they collected the samples influenced the antimicrobial efficacy. Methanol extracts exhibited stronger antibacterial activity compared to water extracts, especially against certain bacterial strains. Although the study suggests that tamarind extracts have limited potential as antimicrobial agents, it emphasizes the need for further research to identify specific antimicrobial compounds within the extracts [40].

Wound Healing Properties of Tamarind Seeds

Mechanism of wound healing involves three distinct phases including the inflammatory phase, the proliferative phase, and the remodeling phase. Each phase is essential for effective wound healing, and any deviations from these normal processes can result in inadequate or chronic healing. Tamarind contains phytochemical compounds such as alkaloids, tannins, and saponins, which important for each phase of wound healing. When an injury occurs, damage to the vascular endothelium triggers the exposure of the basal lamina, resulting in the extravasation of blood components and subsequent platelet activation. Hemostasis is critical for maintaining blood flow in undamaged arteries and stopping blood loss from damaged ones.

Tannins are known to have a haemostatic effect by inhibiting COX-1 metabolism in vivo and reducing platelet aggregation on exposed collagen [41]. During the proliferative phase, the wound exhibits epithelialization, angiogenesis, granulation tissue formation, and collagen deposition. Alkaloids have been reported to promote chemotaxis and epithelialization of wounds [42,43]. Saponins, which are glycoside compounds widely found in plants [44], stimulate collagen formation, which is a crucial factor in wound maturation during the remodeling phase. In a study by Yu et al., researchers explored how *Panax notoginseng* saponins (PNS) promoted fibroblast migration, proliferation, and the expression of fibronectin, collagen I, and collagen III, which aided in the healing of ACL injuries. The findings demonstrated that saponins enhanced collagen and fibronectin expression levels, as well as promoted the proliferation and migration of ACL fibroblasts [45].

CONCLUSION

Tamarind plants are increasingly being recognized as a promising therapeutic option in contemporary medicine. Recent research suggests that extracts from the plant have the potential to enhance cellular functions that are crucial for wound healing, exhibit antimicrobial properties, and provide antioxidant effects. This paper aims to provide a solid scientific foundation, encouraging more basic and applied research to unlock the full potential of this innovative therapeutic agent.

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