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MORALITY BEFORE KNOWLEDGE

Potential of Tamarind (*Tamarindus indica L.*) leaves as funtional food

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ABSTRACT
Background: Public interest in functional foods, which provide health benefits beyond basic nutrition, is growing in Indonesia and worldwide. Despite their recognized medicinal properties, tamarind leaves remain underutilized in functional food applications. This review examines their potential as a valuable local resource for disease prevention. **Methods**: A literature search on "Tamarindus indica leaf" was conducted using databases such as Scopus and Web of Science. Data were collected from sources published between 2010 to 2024, adhering to specific inclusion criteria. Analytical methods included thematic categorization and comparison of findings, with an emphasis on the health benefits and functional food potential of tamarind leaves. **Finding:** Tamarind leaves have been proven to have extensive functional benefits including as a source of antioxidants, antibacterial, antifungal, blood cholesterol lowering agents, antidiarrhea, antiobesity, antidiabetic, anti-inflammatory. Tamarind leaves have the potential to be processed into functional drinks and as a mixture of food products such as snacks. **Conclusion**: Tamarind leaves are an underutilized functional food; further research and innovation are essential for their development. **Novelty/Originality of this article:** There has been no publication that specifically discusses the potential of tamarind leaves as a functional food. This publication is expected to fill this knowledge gap.

KEYWORDS: *Tamarindus indica* leaf; functional food; antioxidant.

1. Introduction

Currently, public attention to food extends beyond merely satisfying hunger to encompass the selection of foods with health benefits that can mitigate the risk of various diseases (Al Saqqa, 2021). The growing awareness of healthy lifestyles among the Indonesian population has emerged as a trend in the modern era. This shift aligns with the increasing number of middle-class residents and the widespread accessibility of health-related information through various print and digital media platforms. Consequently, there has been a heightened public demand for health-supporting facilities, including healthy foods and supplements. Functional foods play a crucial role in human health, serving as a primary source of essential nutrients and functioning as food supplements (Ghazanfar et al., 2022).

The concept of functional foods has rapidly evolved in recent decades, reflecting the growing public awareness of the importance of a healthy diet and balanced lifestyle. Various fruits, vegetables, grains, fish, milk, and meat products are naturally recognized as primary sources of functional foods. Additionally, edible plant parts containing functional

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compounds are included in this category. Currently, the development of functional foods is increasingly broad and diverse. A product can be classified as a functional food if it is a food item (not a capsule, tablet, or powder) derived from natural ingredients, suitable for consumption as part of a diet or daily menu, and possesses a specific function when digested (Winarti, 2010). Beyond fulfilling energy needs, functional foods can also mediate immunomodulatory responses and reduce complications associated with heart disease, osteoporosis, obesity, and cancer. Numerous examples of functional foods exist, particularly those derived from commonly consumed local foods that are subsequently fortified with specific ingredients containing functional compounds. In Indonesia, various types of functional foods have developed and gained circulation; however, specific regulations and standardizations governing functional food products remain absent. The government, through BPOM, currently regulates only the oversight of claims on labels and advertisements for general food, as outlined in the Head of BPOM Regulation No. 13/2016, supplemented by BPOM Regulation No. 1 of 2018 concerning the supervision of special nutritious food. This has resulted in a lack of comprehensive data regarding the development of functional food products in Indonesia (Batubara & Prastya, 2020).

In the global context, the functional food market is experiencing significant growth. According to a report from Grand View Research, the market value is projected to increase at an annual growth rate of 8.5% from 2022 to 2030 (Grand View Research, 2020). This growth is driven by rising consumer demand for food products that are not only flavorful but also offer health benefits. This trend indicates an increasing awareness among consumers regarding the importance of selecting foods that fulfill nutritional needs and contribute to long-term health. In Indonesia, functional foods are also gaining heightened attention, with popular examples including probiotics, omega-3 fatty acids, and foods fortified with vitamins and minerals. For instance, probiotic yogurt containing beneficial bacteria can aid in maintaining digestive health and enhancing the immune system (Gul & Durante-Mangoni, 2024). Additionally, fish oil rich in omega-3 fatty acids has been shown to reduce the risk of heart disease (Innis, 2014). Indonesia's rich plant diversity provides an array of potential food ingredients, with traditional herbs and medicinal plants representing a significant source of functional food. Spice plants, known for their aromatic phytochemical compounds, are widely utilized in cooking as flavoring agents, spices, and preservatives. Various spice plants, such as tamarind, ginger, kencur, turmeric, and cardamom, have been acknowledged for their health benefits (Batubara & Prastya, 2020).

Tamarind (*Tamarindus indica* L.) is commonly found in tropical countries. Originally native to tropical Africa, tamarind has been extensively introduced and naturalized in over 50 countries. The primary production areas are in Asian countries, including India, Thailand, Bangladesh, Sri Lanka, and Indonesia. In the Americas, Mexico and Costa Rica are the largest producers of tamarind (Caluwe et al., 2010). This evergreen plant does not undergo a leaf-fall period, making it suitable for landscaping, while its large size provides excellent shade along highways. Tamarind leaves are compound, featuring long stems and even pinnate leaflets that are brownish or light green, oval-shaped, approximately 1-2.5 cm long, and 4-8 mm wide, with rounded tips that are sometimes notched, rounded bases, and flat edges nearly parallel to each other. The leaf stalks are very short, and the leaf surface is smooth, while the underside is lighter in color. Tamarind produces brown pods containing sticky, sour flesh (Fahima et al., 2022). Based on the Integrated Taxonomic Information System, *Tamarindus indica* is classified under the Kingdom Plantae, Phylum Spermatophyte, Class Angiosperm, and Subclass Dicotyledone. It belongs to the Family Leguminosae and Subfamily *Caesalpiniaceae*. The Genus is Tamarindus, and the Species is *indica* (Bhadoriya et al., 2011).

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Kingdom	: Plantae
Phylum	: Spermatophyte
Class	: Angiosperm
Subclass	: Dicotyledone
Family	: Leguminosae
Subfamily	: Caesalpiniaceae
Genus	: Tamarindus
Species	: indica

Tamarind trees contribute significantly to household food security, provision of wood, nutritional needs, and disease treatment and prevention (Okello et al., 2018). Tamarind is extensively utilized as a raw material for herbal medicine and culinary spices. The primary part of the plant that is utilized is the fruit (60%), followed by the leaves (30%), stems (6%), and seeds (4%) (Fahima et al., 2022). According to a report from the World Health Organization (WHO), tamarind fruit is a source of all essential amino acids except for tryptophan (84%) (Glew et al., 2005; Kuru, 2014). While tamarind leaves, commonly referred to as sinom, are known to possess health benefits similar to those of the fruit, they have not been widely utilized in food consumption. Empirical evidence suggests that tamarind leaves are utilized in herbal medicine to reduce fever and enhance appetite (Fahima et al., 2022), and are also employed in the treatment of inflammation, stomach aches, rheumatism, and sore throats (Wati et al., 2023). Tamarind offers several health benefits by improving and protecting against acute and chronic oxidative stress, which can trigger the development of diseases such as cancer, hypertension, diabetes, cardiovascular dysfunction, and neurodegenerative disorders (Atawodi et al., 2013). So far, traditionally tamarind leaves are widely used in herbal medicine as a functional drink in Indonesia. Although various studies and publications have focused on tamarind plants, there has been limited discussion specifically addressing the potential of tamarind leaves as a functional food. It is essential to explore the functional value of tamarind leaves as a local resource that supports disease prevention and management. This article compiles data from studies and publications on tamarind leaves to provide a deeper understanding of their potential for development into functional foods. The objective of this literature review is to investigate the functional potential of tamarind leaves, which remains largely underappreciated.

2. Methods

This research uses a qualitative approach to investigate and understand the use of tamarind leaves as food. A comprehensive literature search was conducted utilizing the keyword "*Tamarindus indica* leaf" across various databases, including Google Scholar, ScienceDirect, Scopus, and Web of Science. This writing method is descriptive qualitative based on a literature review involving previous research and studies on the use of tamarind leaves as food or traditional medicine. The author gathered information from scientific journals, books, book chapters, reports, and conference proceedings published from 2010 onwards. The data collection process involved several stages, including the identification of relevant articles through keyword searches, the application of inclusion criteria to categorize articles, and the analysis and comparison of findings with related data. The inclusion criteria for this study specified that articles must be published between 2010 and

2024, written in English or Indonesian, and accessible in full text. Subsequently, the articles were organized based on their thematic discussions, and data were systematically collected.

3. Results and Discussion

3.1 General use

Tamarind leaves are utilized as cooking spices, medicinal ingredients, and cosmetic components. In addition, they can be consumed as vegetables and incorporated into various dishes (Caluwe et al., 2010; Lahamado et al., 2017). Characterized by a sour taste, tamarind leaves are commonly used in salads, curries, soups, and a variety of stews, particularly during periods of food scarcity. In northern Ghana, women incorporate tamarind leaves into vegetable soups (Chimsah et al., 2020). They are also prominently featured in Thai cuisine for their sour flavor and unique aroma. In Gambia, children blend tamarind leaves with fig leaves to create chewing gum. In India, while tamarind leaves are recognized for their value as animal feed, their widespread use for this purpose is limited due to potential impacts on tamarind fruit production. The leaves of the wild tamarind tree are consumed by animals such as giraffes and elephants and serve as a high-protein feed source. Additionally, the leaves contain tannins and can yield a red dye, which is employed to impart a yellow hue to cloth dyed with indigo.

In Indonesia, tamarind leaves are regarded as medicinal plants that can be developed into alternative medicine, utilizing safe herbal ingredients that do not produce side effects (Husain et al., 2022). An ethnobotanical study conducted by Fahima (2022) in Lebakrejo village, Purwodadi district, Pasuruan Regency highlighted the diverse uses of tamarind plants for daily needs, including herbal medicine, food ingredients, fuel, tools, animal feed, income sources, customs, cultivation, and road dividers. Specifically, the community employs tamarind leaves as herbal medicine to reduce fever and stimulate appetite, while the young leaves are used as a flavoring agent. Furthermore, tamarind leaves are utilized in traditional medicine to lower blood cholesterol levels. Additionally, tamarind fruit is recognized as a potential medicinal component, particularly for cough remedies (Pakadang & Salim, 2021). The benefits of tamarind leaves include their application as external remedies for conditions such as boils and as internal treatments for ailments like fever and cough (Ihwan et al., 2023). To better illustrate the health benefits of tamarind leaves along their associate bioactive compounds, the following Table 1 summarizes the findings from various studies reviewed in this article.

Table 1. Health benefits and associated bioactive compounds of tamarind leaves

Health Benefit	Associated Bioactive Compounds	References
Antioxidant	Flavonoids, polyphenols, tannins, alkaloids, epicatechin	Escalona-Arranz et al. (2010); Razali et al. (2012); Mbaye et al. (2017); Mbunde et al. (2018)
Antimicrobial (againts bacteria and fungi)	Flavonoids, saponins, tannins, alkaloids, phenolic compounds	Escalona-Arranz et al. (2010); Gumgumjee et al. (2012); Abdallah & Muhammad (2018)
Cholesterol-lowering (hypolipidemic)	Saponins, flavonoids, epicatechin	Aprilia et al. (2017)
Antidiarrheal	Tannins, flavonoids, saponins	Risfianty (2021)
Anti-obesity	Flavonoids, sesquiterpenes, alkaloids, steroids	Kuddus et al. (2020); Wiyono et al. (2022)
Antidiabetic	Flavonoids, polyphenols, α-amylase and α-glucosidase inhibitors	Chigurupati et al. (2020); Nopriantini et al. (2022)
Anti-inflammatory	Flavonoids, saponins, alkaloids	Wati et al. (2023)
Kidney-protective	Antioxidant compounds (flavonoids, polyphenols)	Aprilianti et al. (2023)

3.2 Chemical composition

Tamarind leaves exhibit an average proximate composition of 72.38 ± 1.88 g total sugar, 63.86 ± 2.16 g water, 19.35 g protein, 7.98 g total fiber, 6.77 g fat, and 4.97 g ash per 100 grams of dry leaves. These leaves are notably rich in calcium, magnesium, and potassium. Specifically, each 100 g of dry tamarind leaves contains 1048.55 mg of potassium, 509.14 mg of phosphorus, 511.69 mg of calcium, 275.73 mg of magnesium, 31.07 mg of sodium, 15.81 mg of zinc, and 7.77 mg of copper. Additionally, tamarind leaves can fulfill the requirements for vitamins B1, B2, B3, and other vitamins (Kanfon et al., 2023). To date, no publications have reported on the amino acid composition or the presence of antinutritional agents in tamarind leaves. Regarding secondary metabolites, tamarind leaves contain alkaloids, saponins, and terpenoids in both water and ethanol extracts (Escalona-Arranz et al., 2010; Mbaye et al., 2017; Mbunde et al., 2018).

3.3 Antioxidant sources

Antioxidants are stable molecules or compounds that can donate electrons or hydrogen to free radical molecules, thus neutralizing them and reducing their capacity to initiate free radical chain reactions. These antioxidants play a crucial role in delaying or inhibiting cellular damage primarily through their free radical scavenging properties (Pal et al., 2014). As the human body is unable to synthesize natural antioxidants, they must be obtained from dietary sources such as spices, fruits, and vegetables (Avcil, 2022). Plant antioxidants comprise a diverse array of bioactive compounds, including flavonoids, phenolic compounds, sulfur-containing compounds, tannins, alkaloids, phenolic diterpenes, and vitamins. The extraction of these compounds from plants is typically achieved through various methods, including maceration, distillation for essential oils, and infusion.

Flavonoids and polyphenols are metabolites that are also present in tamarind leaves. Escalona-Arranz et al. (2010) characterized the decoction extracts of both fresh and dried leaves, as well as 30% and 70% ethanol fluid extracts derived from the dried leaves. The decoction was prepared by boiling 10 g and 30 g of leaves (both fresh and dried) in 100 ml of water. The fluid extract was obtained through the percolation method using 30% and 70% ethanol. The 30% w/v fresh leaf decoction extract demonstrated a higher concentration of phenolic compounds with lower flavonoid content (34.73 μg/ml and 0.110 μg/ml, respectively) compared to the 30% w/v dried leaf decoction, which exhibited a lower phenol concentration but higher flavonoid levels (15.14 μg/ml and 0.118 μg/ml, respectively). In contrast, the polyphenols and flavonoids extracted from tamarind leaves using 70% ethanol were found to be higher (18.54 μg/ml and 3.498 μg/ml) compared to those extracted with 30% ethanol (16.47 μg/ml and 1.087 μg/ml). This observation suggests that a decrease in solvent polarity facilitates the extraction of bioactive metabolites from tamarind leaves.

Razali et al. (2012) investigated the effect of solvents with varying polarities on the extraction of phenolic antioxidants from tamarind leaves, seeds, leaf veins, and skin. Tamarind leaves were air-dried and subsequently ground into powder. Extraction from the leaf powder was performed using methanol, ethyl acetate, and hexane at room temperature for 24 hours. The extract was then evaporated, and the residue was dissolved in 10% DMSO and stored at -20°C for analysis of total phenolic content and antioxidant activity using FRAP, DPPH, ABTS, and superoxide anion radical methods. The results indicated that the solvent efficiency for the extraction of phenolic antioxidants followed the order of methanol, followed by ethyl acetate and hexane. The phenolic content ranged from 3.17 to 309 mg GAE/g. The methanol leaf extract (MEL) exhibited the highest phenolic content and demonstrated the strongest DPPH and superoxide radical scavenging activity. Additionally, the methanol leaf extract showed the highest iron reduction activity, while the methanol seed extract acted as the strongest ABTS radical scavenger. A positive correlation was observed between phenolic content and antioxidant activity across the various plant parts. High-Performance Liquid Chromatography (HPLC) analysis of MEL revealed the presence of catechin, epicatechin, quercetin, and isorhamnetin. Overall, methanol proved to be the most effective solvent for extracting phenolic antioxidants from tamarind, with the leaves identified as a particularly valuable source of beneficial natural antioxidants.

Mbaye et al. (2017) conducted a study to analyze the in vitro antioxidant potential of water extracts and fractions of tamarind leaves. The leaves were harvested and dried in a location shielded from direct sunlight. Extraction was performed through decoction using 750 ml of ethanol for 75 grams of leaves over a duration of 30 minutes. Following filtration, the ethanol extract was evaporated to yield a dry residue. Fractionation was achieved by adding 250 ml of warm water to 9 g of the dry extract. Fractions were obtained through liquid-liquid chromatography using solvents of increasing polarity, namely hexane, dichloromethane, ethyl acetate, and water, followed by evaporation to obtain dry extracts. The reduction capacity of each sample was assessed using the DPPH and FRAP methods.

The yield of ethanol decoction extract from tamarind leaves was found to be 8%. The fractions obtained from hexane, dichloromethane, acetyl acetate, and water represented 0.91%, 1.17%, 1.06%, and 2.69% of the leaves, respectively. The evaluation of antioxidant capacity, assessed using the DPPH method, revealed that the ethanol extract exhibited the best IC50 value at 60.53 μg/mL, followed by the water fraction at 71.66 μg/mL. In contrast, the ethyl acetate fraction demonstrated the lowest IC50 value at 453.33 μg/mL. Results from the FRAP method indicated that the highest antioxidant activity, as indicated by optical density, was observed in the ethanol extract (A = 0.066), followed by the hexane fraction (A = 0.016). This study demonstrates that the extract and its chemical fractions possess the ability to reduce DPPH and FRAP, thereby indicating that tamarind leaves exhibit antioxidant activity.

Mbunde et al. (2018) investigated the antioxidant content and activity in tamarind fruit and leaves collected from three agroecological zones in Tanzania, specifically the Morogoro, Tanga, and Dodoma regions. Tamarind leaves were air-dried in the shade at room temperature and ground into powder. Ten grams of both tamarind leaf and fruit pulp powder were extracted using 99.9% methanol for 48 hours at 30-33°C. The extracts were filtered through Whatman No. 1 filter paper and evaporated under reduced pressure at 40°C. The resulting crude extracts were analyzed for total phenolic and flavonoid contents, as well as for antioxidant activity. Total phenolic content exhibited significant variation across all fruit and leaf extracts, ranging from 1994.4 ± 530.77 to 17874.67 ± 5234 mg GAE/100 g. Similarly, the total flavonoid content in tamarind leaf and fruit extracts ranged from 880 ± 609.45 to 11483.11 ± 2559.67 mg CE/100 g dry weight. A significant difference was observed between the antioxidant activities of the leaf (54.39 ± 0.13%) and fruit extracts (40.11 ± 0.03%). Notably, tamarind leaf extract demonstrated markedly higher radical scavenging activity compared to the fruit extract. The antioxidant activity in the fruit extract, expressed as a percentage, varied between 29.27 ± 0.06% and 40.11 ± 0.03%, whereas the leaf extract activity ranged from 22.33 ± 0.08% to 54.39 ± 0.13%. The radical scavenging activity of the leaf extract from the Tanga region was the highest, followed by the Morogoro region and, finally, the Dodoma region. These findings align with the observed antioxidant activity, which was positively correlated with total phenolic and flavonoid contents. It has been reported that geographical location and climatic conditions significantly influence the quantity and activity of antioxidants present in tamarind leaves and fruits. The results of this study suggest that tamarind can serve as an economical source of antioxidants.

3.4 Antimicrobial activity

Escalona-Arranz et al. (2010) investigated the antimicrobial properties of water extracts from both fresh and dried tamarind leaf decoctions, 30% and 70% ethanol extracts of dried leaves, and essential oils derived from tamarind leaves against a range of microorganisms, including Bacillus subtilis, Enterococcus faecalis, Staphylococcus aureus, Escherichia coli, Salmonella typhimurium, Pseudomonas aeruginosa, and Candida albicans. The decoction extract demonstrated activity primarily against B. subtilis. The 30% and 70%

ethanol extracts exhibited activity against S. aureus, E. faecalis, B. subtilis, P. aeruginosa, and E. coli, while the essential oil was effective against nearly all tested microorganisms, with the exception of P. aeruginosa. Both the decoction and ethanol extracts were found to be more effective against gram-positive bacteria than gram-negative bacteria.

Gumgumjee et al. (2012) evaluated the antibacterial properties of water extracts and organic solvent extracts (ethanol, petroleum ether, diethyl ether, ethyl acetate, chloroform, and methanol) from tamarind leaves against seven bacterial strains, comprising three gram-negative bacteria (E. coli, Klebsiella pneumoniae, P. aeruginosa) and four gram-positive bacteria (B. subtilis, S. aureus, methicillin-susceptible Staphylococcus aureus (MRSA), Micrococcus luteus). Additionally, antifungal activity was assessed against four fungal species: Aspergillus flavus, Aspergillus fumigatus, Aspergillus niger, and C. albicans. The ethanol extract demonstrated the highest activity against the tested bacterial strains, followed by the methanol extract and ethyl acetate extract. Among the gram-positive bacteria, the ethanol extract exhibited the most significant activity against Micrococcus luteus, followed by Staphylococcus aureus, MRSA, and Bacillus subtilis in that order. The ethanol extract of tamarind leaves demonstrated strong antibacterial activity against gram-negative bacteria, particularly K. pneumoniae, followed by E. coli and P. aeruginosa. In contrast, the water extract exhibited the lowest antibacterial activity among the solvent extracts. The antifungal activity of the ethanol extract was robust, with the methanol extract also showing significant activity against all tested fungi, except for A. flavus.

Abdallah and Muhammad (2018) conducted a phytochemical analysis and assessed the antibacterial efficacy of tamarind leaf and fruit extracts against clinical isolates of E. coli and Shigella sp. derived from stool samples of pregnant women attending the Potiskum antenatal clinic in Yobe State, Nigeria. The initial phytochemical analysis was performed using standard laboratory methods, while the agar well diffusion method was employed to evaluate the antibacterial activity of the extracts. Phytochemical screening of tamarind leaf and fruit extracts revealed the presence of alkaloids, glycosides, saponins, tannins, anthraquinones, steroids, flavonoids, reducing sugars, terpenoids, and phenols. The antibacterial efficacy of the extracts against the isolates indicated that the extracts were active, with the methanol extract exhibiting higher activity (average inhibition zone of 14.48 mm) compared to the water extract (12.52 mm). Furthermore, the results indicated that Escherichia coli was more sensitive to the tamarind extract, with an average inhibition zone of 14.62 mm, compared to Shigella sp., which showed an average inhibition zone of 11.47 mm. The minimum inhibitory concentration (MIC) of the extracts demonstrated that dilutions of various concentrations of water and methanol extracts inhibited the growth of the isolates at concentrations ranging from 3.125 to 25 mg/ml. Statistical analysis revealed a significant difference in extract activity against the isolates at $p < 0.05$. These findings support the potential use of tamarind leaf and fruit extracts for medicinal purposes.

3.5 Therapeutic activity

Aprilia et al. (2017) conducted a study to assess the effects of lowering blood cholesterol and the antioxidant activity of tamarind leaf extract in 25 rats. Tamarind leaf extract is recognized for its high saponin content, which can regulate lipid levels by inhibiting lipid absorption in the intestine. Notably, the saponin concentration in the 70% ethanol extract of tamarind leaves surpasses that of flavonoids. However, the study did not provide details regarding the production of the tamarind leaf extract. The extract was administered in three dosages: 0.93 g/kg BW, 1.86 g/kg BW, and 3.73 g/kg BW. The test subjects were 8-week-old male albino Wistar rats. Between days 8 and 22, the rats were fed a hypercholesterol diet. On day 24, the rats continued with the hypercholesterol diet while receiving interventions for two weeks, which included a CMC solution, Ezetimibe at a dosage of 1.26 g/kg BW/day, and the three varying doses of tamarind leaf extract. On day 33, a blood analysis was conducted to evaluate the outcomes post-intervention. The results indicated that tamarind leaf extract significantly reduced total cholesterol and triglyceride levels, while high-density lipoprotein (HDL) cholesterol levels exhibited a notable increase.

The presence of saponins, flavonoids, and epicatechin in tamarind leaf extract plays a vital role in cholesterol reduction and hypolipidemic effects. Specifically, saponins bind to bile acids to form large micelles, which inhibit cholesterol absorption by microvilli on the intestinal epithelium, consequently reducing total plasma cholesterol concentration. Flavonoids enhance the activation of LDL-C receptors in the liver, facilitating faster clearance of LDL-C and lowering triglyceride levels. Additionally, epicatechin contributes to lowering triglycerides and promoting the excretion of free fatty acids and sterol acids through feces. The flavonoids, polyphenols, and tannins present in tamarind leaf extract also function as antioxidants, increasing the activity of antioxidant enzymes such as glutathione peroxidase (GPx), catalase (CAT), and superoxide dismutase (SOD). This action makes lipids more resistant to oxidation and helps prevent the formation of atherogenic plaque, thereby potentially reducing the risk of atherosclerosis.

Risfianty (2021) developed an anti-diarrheal drug derived from tamarind leaf waste, formulated as a tea drink. This initiative addresses the adverse side effects associated with the continuous consumption of chemical drugs for diarrhea, highlighting the need for alternative sources of anti-diarrheal treatments that minimize harmful effects on the body. The study commenced with the preparation of water extracts from both fresh young and old tamarind leaves, using 250 g of leaves combined with 1000 ml of distilled water. The mixture was then heated to a temperature of 80-90°C for 60 minutes with occasional stirring. Following this, the mixture was filtered, and the water extract was evaporated to obtain a concentrated tamarind leaf extract. The extract was analyzed for tannin content using 1% FeCl3 and a UV-VIS spectrophotometer. Subsequently, testing was conducted using male Mus musculus as experimental subjects, which were divided into four groups of five animals each. Group I served as the negative control, Group II received 0.5 ml/20 gBW of castor oil as the positive control, Group III was administered 800 mg/kgBW of young tamarind leaf water extract, and Group IV was given 800 mg/kgBW of old tamarind leaf water extract. The results indicated that the tannin content in the fresh old tamarind leaf water extract was higher, as determined by the 1% FeCl3 and UV-VIS spectrophotometer tests, and this extract proved to be more effective in alleviating diarrhea in the Mus musculus subjects, as evidenced by changes in fecal consistency. Tannin, an active compound found in secondary metabolites, possesses various properties, including astringent, anti-diarrheal, antibacterial, and antioxidant effects. The antibacterial activity of tannins is attributed to their ability to penetrate bacterial cells and coagulate protoplasm as a result of the lysis of bacterial walls caused by saponins and flavonoids. Additionally, the antibacterial mechanism of phenolic compounds involves disrupting the bacterial cytoplasmic membrane, which affects active transport and proton gradients. The findings of this study may serve as a reference for the utilization of fresh old tamarind leaves as an alternative medicine for treating diarrhea.

Kuddus et al. (2020) investigated the anti-obesity effects of ethanol extract of tamarind leaves on obese Wistar rats subjected to a high-fat diet. The study examined biochemical parameters and gene expression patterns of transcription factors critical to adipocyte differentiation and enzymes involved in lipid metabolism. The findings demonstrated that oral administration of antioxidant-rich tamarind leaf extract (TILE) for eight weeks significantly mitigated oxidative stress induced by a high-fat diet (HFD) by enhancing the activities of antioxidant enzymes. Additionally, TILE reduced mRNA levels of transcription factors regulating adipogenesis and lipogenic enzymes while increasing transcript levels of the lipolytic enzyme hormone-sensitive lipase (HSL). Consequently, TILE led to a reduction in triglycerides, total cholesterol, LDL cholesterol, and very low-density lipoprotein (VLDL) cholesterol in serum, along with a coordinated decrease in adipose tissue weight, liver weight, and body weight.

Chigurupati et al. (2020) examined the antioxidant and antidiabetic activities of Malaysian tamarind leaf extract using two extraction methods: maceration (*Tamarindus indica* maceration extraction, TIME) and Soxhlet extraction (*Tamarindus indica* soxhlet extraction, TISE). The total phenolic (TP) content for TIME was found to be 1.80 mg gallic acid equivalent (GAE)/g, while TISE had a TP content of 1.01 mg GAE/g. The total flavonoid

(TF) content for TIME was 1.44 mg rutin equivalent (RUE)/g, compared to 1.04 mg RUE/g for TISE. Due to its higher TP and TF content, TIME was selected for further research. Radical scavenging assays using 2,2-diphenyl-1-picrylhydrazyl and 2,2'azino-bis-3-ethylbenzothiazoline-6-sulfonic acid indicated that the radical scavenging capacities of TIME were 1.42±0.3 μg/ml and 1.62±0.66 μg/ml, respectively. In vitro antidiabetic assays using α-amylase and α-glucosidase inhibition demonstrated the antidiabetic capabilities of TIME at 2.24±0.07 μg/ml and 2.26±0.07 μg/ml, respectively. Acute oral toxicity studies in rats indicated that TIME was safe at doses up to 2,000 mg/kg body weight (BW). Additionally, treatment with 200 mg/kg BW of TIME significantly reduced elevated blood glucose levels compared to glucose-treated and streptozotocin-induced normoglycemic diabetic rats. The results of this study suggest that the maceration extract of Malaysian tamarind possesses therapeutic potential as a natural antioxidant and antidiabetic agent.

Wiyono et al. (2022) conducted an analysis of the phytochemicals present in tamarind leaf extracts cultivated in various climatic conditions to assess their antilipase and antiamylase activities. Several therapeutic strategies for treating and preventing obesity have been proposed; however, pharmacotherapy options such as orlistat, sibutramine, or cannabinoid receptor antagonists are associated with side effects. Tamarind leaves are believed to possess lipid-lowering properties, suggesting their potential use as antiobesity agents. The phytochemical profiles of tamarind leaf extracts from diverse tropical zones were examined using ultra-high performance liquid chromatography coupled with electrospray ionization high-resolution mass spectrometry (UHPLC-ESI-MS). Parameters related to antiobesity properties were evaluated, including antioxidant capacity, antilipase and antiamylase activities, total phenolic and flavonoid contents, and vitexin levels in the extract. The enzymes pancreatin and p-nitrophenylbutyrate were utilized to assess antilipase activity, while the antiamylase activity was determined by measuring the hydrolysis of starch by pancreatin in the presence of the extract. Notably, tamarind leaves grown in a tropical monsoon climate exhibited a significant inhibition of lipase enzyme activity at a concentration of 3.8 μg/ml ($p = 0.0026$). It is hypothesized that, in addition to flavonoids, sesquiterpenes, alkaloids, and steroids contribute to the pronounced synergistic lipase inhibitory activity observed. Enzyme kinetics analysis indicated that the inhibition pattern resembles mixed-mode inhibition. This information is valuable for the standardization of tamarind leaf extract for applications in herbal medicine development.

Wati et al. (2023) investigated the potential of tamarind leaf extract as an anti-inflammatory agent in Wistar rats. This study involved experimental rats divided into five groups: Group I received Na.CMC, Group II was administered sodium diclofenac at a dose of 5.136 mg/kg body weight (BW), and Groups III, IV, and V received ethanol extract of tamarind leaves at doses of 250, 500, and 1000 mg/kg BW, respectively. The test animals were induced with 1% λ-carrageenan intraplantarly one hour following the oral administration of the test preparation. The volume and thickness of rat edema were measured before and after induction at 1-hour intervals for a total duration of 7 hours using a plethysmometer and caliper. The results indicated that the group receiving the 1000 mg/kg BW extract exhibited an anti-inflammatory effect that was not significantly different from that of the sodium diclofenac group receiving 5.136 mg/kg BW. Consequently, the findings suggest that tamarind leaf extract possesses anti-inflammatory properties at an effective dose of 1000 mg/kg BW.

Aprilianti et al. (2023) conducted a study examining the effects of tamarind leaf ethanol extract on kidney urea levels, histology, and histophotometry by measuring the space between the Bowman capsules of white rats (Rattus norvegicus) induced by used cooking oil. The study utilized experimental animals divided into five groups, with each group housed in a distinct cage. The selected experimental subjects were male white rats (Rattus norvegicus) meeting specific criteria: body weight between 148-166 grams, age of 2-3 months, healthy physical condition, clean white fur, and normal behavior. The cages were plastic boxes with lids and bases made from rice husks. Prior to treatment, the animals underwent acclimatization to adjust to their new environment. Acclimatized male white rats were weighed to determine the appropriate extract dosage, after which the extract was diluted with 1% CMC. A total of 25 rats were divided into five groups with five replications: negative control (1% CMC for 28 days), positive control (1.5 ml used cooking oil for 28 days), and treatment groups 1, 2, and 3, which received 1.5 ml of used cooking oil along with ethanol extract of tamarind leaves at doses of 150 mg/kg BW, 200 mg/kg BW, and 250 mg/kg BW for 28 days. The ethanol extract of tamarind leaves was prepared from leaves that had been cleaned and dried under direct sunlight, covered with a black cloth. The dried leaves were ground using a blender to obtain simplicia powder, which was then sieved. The resulting simplicia powder was extracted using the maceration method with 96% ethanol solvent at a ratio of 1:10 for 48 hours, with periodic stirring. The maceration mixture was filtered to collect the filtrate, which was subsequently concentrated using a rotary evaporator. The extract was then diluted with 1% CMC, with dosage calculated according to the treatment groups. The tests included qualitative screening of active compounds using color reagents to identify secondary metabolites. The examination results indicated a highly significant difference between the negative control group (18.89 ± 1.924) and the positive control group (40.00 ± 1.58), demonstrating that the administration of 1.5 ml of used cooking oil for 28 days adversely affected kidney function. Treatment groups receiving graded doses of 150, 200, and 250 mg/kg BW/day exhibited varying outcomes due to the administration of the tamarind leaf ethanol extract. Notably, treatment group 3, as determined by the Duncan test, showed results (21.00 ± 3.16) that were not significantly different from the negative control group (18.89 ± 1.924). This finding indicates that the ethanol extract of tamarind leaves at a dose of 250 mg/kg BW is effective in mitigating free radical damage induced by used cooking oil and significantly reduces average urea levels.

3.6 Potential for tamarind leaf processing as functional food

Tamarind leaves are an often-overlooked component of the tamarind plant. The processing of tamarind leaves can be conducted using various methods, depending on the intended purpose and desired end product. To date, tamarind leaves have been utilized in herbal medicine as well as in culinary applications to enhance flavor. Given the numerous functional potentials of tamarind leaves mentioned above, their role can be maximized by developing them into a functional drink, as they contain components with high solubility that can disperse evenly in such beverages. In liquid form, functional components can be easily formulated and readily absorbed by the body after consumption (Winarti, 2010).

Research indicates that tamarind leaf extract is rich in polyphenol and flavonoid compounds, which serve as antioxidants and provide benefits such as antimicrobial, hypolipidemic, antidiabetic, and anti-inflammatory effects. Tamarind leaf extract can be extracted and formulated into functional drinks that are abundant in antioxidants and nutrients. In a health context, functional drinks are products that not only provide hydration but also have positive effects on overall health. These beverages can contribute to disease prevention and treatment, enhance optimal body function, and improve immune response (Ryadha S et al., 2021). Given their diverse potential, it is vital to further explore the methods for processing and serving tamarind leaves as functional drinks.

Nopriantini (2022) conducted an organoleptic evaluation of a tamarind leaf tea infusion formulation for patients with type 2 diabetes mellitus. The inhibition of α-amylase by tamarind leaves presents a potential alternative treatment for this condition. The formulation consisting of 2 g of tamarind leaves with 100 ml of water received favorable acceptability scores in terms of aroma, taste, and color. The resulting tea offers a refreshing flavor derived from the tamarind leaves, without an overpowering sour taste. However, increasing the quantity of tamarind leaves results in a more robust and overly sour flavor that may be unpalatable.

Processing tamarind leaves into functional beverages can be accomplished through simple methods such as boiling or creating an extract. These processes not only preserve nutrients and bioactive compounds but also facilitate consumption. Research by Escallona-Arranz et al. (2010) indicates that boiling tamarind leaves effectively extracts bioactive compounds that are beneficial to health. After boiling, the water can be filtered and served as either a hot or cold drink. In addition to boiling, tamarind leaves can also be processed into extracts or powders. This method enhances the retention of nutrients and bioactive compounds. Tamarind leaf extract can be combined with other ingredients, such as honey or lemon, to improve its flavor and health benefits. Research by Carr et al. (2017) demonstrates that this combination not only enhances taste but also increases the vitamin C content in beverages.

In terms of presentation, it is essential to consider the aesthetic and packaging aspects. Consumers today show a growing interest in beverage products that are not only healthy but also visually appealing (Hallak et al., 2022). Therefore, the packaging of functional drinks made from tamarind leaves must be thoughtfully designed to attract consumer attention. An appealing packaging design can enhance the product's appeal and encourage consumers to try it. Given the various processing and serving methods available, there is significant potential for developing tamarind leaves as a functional beverage. Further research is necessary to identify optimal dosages, efficient extraction methods, and product development strategies that resonate with consumers. Through this approach, there is hope that tamarind leaves can emerge as an innovative ingredient in the healthy beverage industry in Indonesia.

In the context of the food industry, innovation in the use of natural ingredients is increasingly essential. One potential avenue for innovation is the development of healthy snacks utilizing tamarind leaves. One approach is to create a snack product based on tamarind leaf powder. The process of converting tamarind leaves into powder can involve drying and grinding, resulting in a versatile ingredient suitable for various formulations. Healthy snacks containing tamarind leaves can present an appealing alternative, both in terms of flavor and health benefits. Tamarind leaves are the cheapest source of nutrients such as vitamins, minerals, and dietary fiber that help improve micronutrient deficiencies. Considering the abundant availability of tamarind leaves in the local area and due to the increasing consumer demand for the consumption of sweet foods such as snack bars and chocolate, an effort was made to develop chocolate sweet products by combining dried tamarind leaf powder which complements nutrients such as fiber, protein, minerals, vitamin C, and antioxidants. The high availability of tamarind leaves in India and considering its health benefits, prompted Harshita et al. (2021) to utilize and maintain the nutritional content of tamarind leaves by drying and mixing them into chocolate products, a snack that is popular with all groups, especially school children and teenagers. Tamarind leaves are washed, dried and then blanched for 2 minutes before finally being dried for 3 hours in the oven. The dried tamarind leaves are then ground into powder. As much as 5%, 10% and 15% tamarind leaf powder are mixed into three chocolate variants, namely light, dark and a combination of light and dark (1:1) which have been melted, then stirred, poured into molds and cooled in the refrigerator. The chocolate products that have been made are then analyzed proximately and sensory evaluations are carried out. Chocolate products with a formula of 5% tamarind leaf powder are more acceptable to panelists than formulas of 10 and 15% tamarind leaf powder. The addition of 5% tamarind leaf powder is equivalent to 16 g of fresh leaves which provides a range of 0.928 g of protein, 0.2 g of ash, 0.07 g of fat, 10.7 mg of calcium, 0.45 mg of iron, 74.4 mg of potassium, 2.14 mg of sodium, 0.14 mg of zinc, 3.55 mg of vitamin C per 100 g of chocolate product. Further research that can be developed is to increase the sensory acceptance of the addition of tamarind leaf powder in a much larger concentration, because the addition of 15% tamarind leaf powder is equivalent to 48 g of fresh leaves in 100 g of chocolate product which can enrich the content of micronutrients and fiber. The use of 1:1 light chocolate dark chocolate is more recommended because it minimizes sugar content and is richer in fiber, flavonoids and phenols compared to the use of light chocolate alone so it is safer for children and adults.

In addition to chocolate products, tamarind leaves can also be integrated into ready-to-eat jelly. The development of low-calorie jelly featuring tamarind leaf extract represents an innovative approach to healthy food product variations aimed at weight management and calorie reduction for diabetics (Ahdiah et al., 2023). Ahdiah et al. (2023) introduced the Jellowry product as a functional food innovation, utilizing porang tuber flour in combination with tamarind leaf powder. Porang tubers, rich in glucomannan, may support weight loss and help inhibit increases in total cholesterol and triglycerides, while tamarind leaf powder serves as a complementary treatment for type 2 diabetes mellitus. Jellowry is conveniently packaged in pouches for ease of consumption and portability. The innovation in healthy snack processing using tamarind leaves is crucial for engaging consumer interest and addressing the demands of a growing market. By harnessing the potential of tamarind leaves, it is anticipated that snack products can be developed that are both delicious and health-promoting.

4. Conclusions

Tamarind leaves, as a functional food, provide a range of significant health benefits. The potential for utilizing tamarind leaves in this capacity remains largely untapped. Ongoing research and innovation in the processing and formulation of tamarind leaf-based products must be prioritized to foster a healthy and sustainable functional food market. Further investigation is crucial to fully explore the benefits and potential of tamarind leaves. Additionally, the development of plant-based functional foods is imperative, as the effectiveness of the processing methods employed—ranging from raw materials to finished products—plays a critical role in preserving the content of active compounds.

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