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Review Article

Study of Traditional Uses, Extraction Procedures, Phytochemical Constituents, and Pharmacological Properties of *Tiliacora triandra*

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Tiliacora triandra (Colebr.) Diels (Menispermaceae family) is a Southeast Asian angiosperm herb. Traditional medicine in these areas often includes the use of plant parts. Plant extracts are highly effective against various infections including bacterial, fungal, viral, and parasitic. The leaves and root extracts are used to treat gastrointestinal diseases, hypertension, diabetes, skin diseases, and malaria as an antipyretic, detoxification agent, anti-inflammatory, anticancer, and immunomodulator. Bioactive compounds contained in *T. triandra* include phenolic compounds, alkaloids, flavonoids, terpenoids, fatty acids, essential amino acids, peptides, carbohydrates, vitamins, and nucleic acid precursors. Despite the plant species' abundance of bioactive compounds, there is very little in vivo and clinical proof of its pharmacological significance. The present review focuses on the phytochemical configurations, extraction methods for major bioactive compounds, and pharmacology of *T. triandra*, in light of its potent medicinal values.

1. Background

Tiliacora triandra (Colebr.) Diels, locally known as "Yanang," is an angiosperm plant species from the Menispermaceae family, which consists mainly of twining shrubs or small trees and includes 64 genera and 379 species. It is primarily found in tropical countries (https://www.theplantlist.org/browse/A/Menispermaceae/). It is a climbing plant native

to Southeast Asian countries, particularly Thailand and Vietnam. According to the World Flora Online and Plant List databases, the species name (*Tiliacora triandra*) is unresolved, and its status is still uncertain (Figure 1). Besides, the plant list databases also state that it is synonymous with some other species (https://www.theplantlist.org/tpl1.1/record/kew-2517123; https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:581568-1#synonyms). The color of its flowers is yellow. The leaves are commonly used in Thai and Laos cuisine, and the roots and leaves are used in folk medicine in many Southeastern Asian countries [1–3]. Some reports state that leaves and roots from this plant species are used as an antipyretic, detoxification agent, anti-inflammatory agent, anticancer, antibacterial, and immunomodulator. Furthermore, it has been used to treat gastrointestinal diseases, hypertension, diabetes, skin diseases, and malaria [4, 5].

Different chronic diseases continue to increase worldwide with treatments that are not sufficiently effective and demand new medication options. Natural products are an alternative like the Mahanil-Tang-Thong formulation is a Thai herbal formulation used for various medicinal purposes. Chania et al. [6] demonstrated the antimalarial activity of medicinal plants in the Mahanil-Tang-Thong formulation. Recently, Maki et al. [7] investigated the anti-inflammatory activity and liver cancer cytotoxicity of Poh-Pu remedy from traditional Thai medicine. These compounds from natural sources contribute to some ailments and improve patients' quality of life. *T. triandra* is still a valued plant with high nutritional and medical potentials and is in the process of further basic, preclinical, and clinical research. This work aims to present an analysis of recent and relevant information on the pharmacological study of *T. triandra* against infectious, anticancer, antidiabetic, and neuroprotective processes, among others, as an indication of the relevance of this plant for wide traditional uses.

2. Traditional Uses

Some medications' high costs and harmful effects have encouraged the pursuit of effective and low-priced substitutes obtained from nature. *T. triandra*, often known as bamboo grass, has been successfully used by indigenous populations throughout Southeast Asia to treat various illnesses and problems. There are few studies regarding the ethnopharmacological potential of *T. triandra*, which is shown in Figure 2. Leaves and roots of *T. triandra* have been traditionally used in folk medicine in Thailand and Asian countries to treat several illnesses, including malaria, gastrointestinal diseases, alcohol intoxication, skin diseases, hypertension, and fever [8].

These effects are related to their phytochemical content. Additionally, aqueous extracts of *T. triandra* leaves have been used in Thai cuisine [9]. Likewise, ethnobotanical reports on *T. triandra* have led scientists to evaluate its biological properties such as antiproliferative, antioxidant, antidiabetic, anti-inflammatory, and neuroprotective potential. *T. triandra* is quite effective against peptic ulcers and can act as an antidote for food poisoning and environmental toxicants [8, 10, 11]. Moreover, various reports have indicated that *T. triandra* may be beneficial to treat diabetes [4], tuberculosis [12], increased cholesterol [1], cancer [2, 13], and various neurological conditions [5, 14–16]. Their phytochemical composition is considered responsible for these effects. As a result, understanding Ayurveda, ethnobotany, and information on tribal medicinal sources will be critical in producing pharmaceuticals with low or no adverse effects.

3. Extraction and Isolation Procedures of Major Compounds from *T. triandra*

Most procedures for extracting active compounds from *T. triandra* involve ethanol or methanol as the solvent. However, those methods exhibit several differences, depending on the substances of interest to be extracted, the wanted methodological innovations, and the desired pharmaceutical properties (Table 1). In this respect, in a pioneer study, Wiriyachitra and Phuriyakorn [21] extracted alkaloids from 1kg of roots of *T. triandra* with methanol/aqueous chloroform/ammonia (15 : 5 : 1) at room temperature. The authors concentrated their extract at reduced pressure, dissolved it in anhydrous acetic acid, and poured it into water. This blend was clarified and basified with ammonia to precipitate the alkaloids in chloroform. Afterward, the authors evaporated the chloroform extract and obtained the raw alkaloids with an efficiency of 8%. Finally, the authors separated the alkaloids on a silica gel column through chromatography. The alkaloids tiliacorinine, nortiliacorinine A, tiliacorine, and tiliacorinine 2′-N-oxide were obtained with this procedure.

Another study employed a sophisticated design to extract polysaccharide gum from the leaves of *T. triandra* [22]. The authors evaluated the effect of temperature on extraction (25–85°C), time of extraction (60–180 min), and dried leaf: water ratio (1 : 5–1 : 15) through a central composite design with a quadratic model. In all cases, the mixture was extracted with three volumes of 95% ethanol (w/v). The authors found that gum extraction's optimal conditions were an extraction temperature of 85°C, extraction time of 100min, and dried leaf:water ratio of 1 : 6. Likewise, their findings indicated that their experimental design efficiently optimized the gum extraction conditions from the plant. In a similar study, Singthong et al. [24] explored the extraction competencies of bioactive compounds from *T. triandra* using various solvents (water, ethanol, and acetone). Their results revealed that water extraction is the most suitable method to extract phenolic compounds because it produces the highest yield. Besides alkaloids and polyphenols, *T. triandra* contains other bioactive components, which were extracted by Duangjai and Saokaew, [1]. They proposed a method to extract the plants' leaf fatty acids by consecutively macerated with hexane, dichloromethane, methanol, and water. The results indicated that hexane extraction was effective in obtaining fatty acids. Rahman et al. [25] aimed to find the phytochemical components from the stem bark of *T. triandra*. The authors mixed approximately 150g of stem bark powder with methanol (80%), and the mixture was stored for two weeks with occasional shaking. The extracts

Figure 1: Photo of the whole plant and various parts of *Tiliacora triandra* (Reproduced under the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported License, https://tropical.theferns.info/viewtropical.php?id=Tiliacora+triandra, accessed on 2020.12.09 [55]).

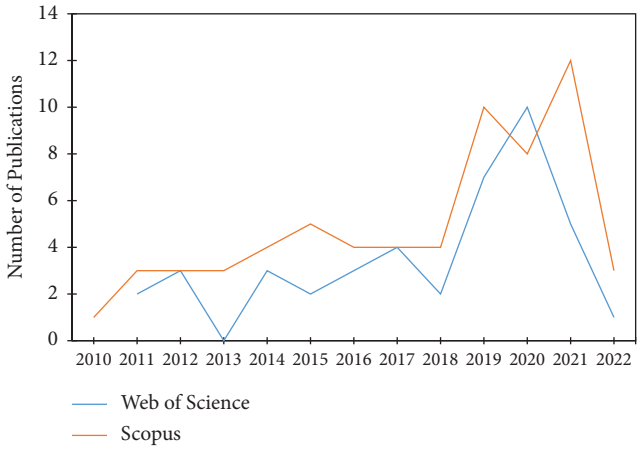

Figure 2: Publications registered in Web of Science and Scopus databases using the term "*T. triandra*" from 2010 to 2022.

were filtered and then dried at 50°C under decreasing pressure. The authors reported the extraction of terpenoids, flavonoids, phenolics, saponins, alkaloids, and cardiac glycosides; however, their exact quantities were not reported.

Finally, two very recent studies reported the isolation of at least 26 compounds that had not been described previously in *T. triandra* [4, 17] (Table 1). In the first research [17], the authors macerated 800 g of leaves and 500 g of twigs from *T. triandra* in 95% ethanol; afterward, the blending was filtered and vaporized to obtain the raw ethanol extract (84.2 g), which was mixed with water. The blend was partitioned between ethyl acetate and hexane, and the soluble fractions were isolated through column chromatography. Then, the subfractions found by chromatography were subjected to additional purification by reverse-phase HPLC. The second study utilized a similar approach coupled with GC-MS analysis to identify new phytochemical components of the plant [4]. The above procedures resulted in separating and identifying 6 [17] and 18 [4] new compounds, respectively. Therefore, the development and perfection of the extraction techniques and the incorporation of more innovative technologies will allow easy identification of new bioactive compounds from the *T. triandra* plant species in the forthcoming years.

Furthermore, several bioactive properties of the identified phytochemicals are presented in Table 2. Besides identifying phytochemicals in the leaves, twigs, and stem bark of this plant, these plant parts also exhibited several bioactive properties like antioxidant, anticancer, antimicrobial, and antiproliferative, among others. Moreover, some bioactive compounds have shown outstanding results against some metabolic syndrome disorders (e.g., lowering lipids and sugars) (Table 2).

4. Phytochemical Constituents of *Tiliacora triandra*

Numerous research groups have explored the active phytochemical compounds responsible for the therapeutic effects of this herb. According to these investigations, *T. triandra* and its components include a variety of bioactive

Table 1: Phytochemical constituents of *Tiliacora triandra*.

Plant species name Compound	Chemical structure	Reference Part of the plant	Reference
Decamethyltetrasiloxane Dibenzylhydroxylamine Dihydroxydimethylsilane Eicosanoic acid Hexadecamethylheptasiloxane Hexamethylcyclotrisiloxane Methyl-N-hydroxybenzenecarboximidoate Methyl tetradic-5-ynoate Pentadecanoic acid		Twigs and leaves	[4]
1-Cyclododecylethanone	0		
1,1,3,3,5,5,7,7,9,9,11,11,13,13-Tetradecamethylheptasiloxane	1		
2-Heptadecanone	2		
Tris-(trimethylsilyl)borate	3		
Ethyl linoleate	4		
Ethyl linolenate	5		
Pheophorbide A ethyl ester	6		
Pheophorbide A	7	Twigs and leaves	[17]
5,7-Dihydroxy-6-oxoheptadecanoic acid	8		
5-Hydroxymethyl-2-furancarboxaldehyde Neophytadiene	0		
Oleamide	1		
Oleic acid	2		
Phytol	3	Leaves	[9]
Vitamin E	4		
2-(Cyclohexen-1-yl)acetic acid	5		
2,6-Dimethyl-3-(methoxymethyl)-benzoquinone	6		
Palmitic acid	7		
Petroselinic acid Stearic acid	8	Leaves	[2]
Nortiliacorinine A	0	Root	[12, 18–21]
Tiliacorine	1		
Tiliacorinine 2′-N-oxide	2	Root	[12, 18, 20]
Oxoanolobine	3	Leaves	[13]
L-Arabinose	4		
D-Galactose	5		
L-Rhamnose	6	Leaves	[22]
Catechin	7		
Chlorophyll A	8		
Chlorophyll B Isoquercetin	0		
Rutin	1		
Tannic acid	2		[23]
Quercetin	3		

Table 2: Studies on the bioactive potential of *Tiliacora triandra* plant parts and their respective identified compounds.

Plant part	Identified chemicals	Bioactive effect	Type of extract	Dose range	Test type (in vivo/in vitro)	Model use	References
Mature leaves	Vitamin E, phytol, and 1-cyclohexenylacetic acid	Antioxidant (DPPH method), cytotoxicity and genotoxicity	Methanol	8.4 mg/ml (DPPH), 10 mg/ml (lymphocyte), and 0.41 mg/ml (HeLa cells)	In vitro	Lymphocytes and HeLa cells	[9]
Leaves	Hexadecenoic, octadecanoic, and (z)-6-octadecanoic acids	Cytotoxicity against lung cancer	Hexane	125 μg/mL	3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay	A549RT-eto cells	[2]
Leaves and twigs	n-Palmitic acid, dibenzylhydroxylamine, oleic acid, and stearic acid	Antidiabetic	Ethanol	400 mg/kg	Hypoglycemic activity	HOMA-IR and HOMA-β induced rats	[4]
Leaves and twigs	Pheophorbide A, ethyl pheophorbide, ethyl linoleate, ethyl-5,7-dihydroxy-6-oxooctadecanoate, and 5,7-dihydroxy-6-oxoheptadecanoic acid	α-Glucosidase and α-amylase	Ethyl acetate	α-Glucosidase activity at 11.58–424.06μM and α-amylase at 26.27μM	α-Glucosidase and α-amylase	—	[17]
Aerial parts	Gallic acid, cyanidin, and quercetin	CAT, GSH-Px, and SOD activities	Water	Spatial memory (400 mg·kg^{-1}BW), AChE activity in the hippocampus (200mg·kg^{-1}BW), oxidative stress (100, 200, and 400 mg·kg^{-1}BW)	Acute toxicity and antioxidant enzyme expression	Male Wistar rats	[5]
Stem barks	Alkaloids, cardiac glycosides, flavonoids, phenolic compounds, saponins, and terpenoids	Antimicrobial and antifungal activities	Methanol	62.5 ug/mL	Minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC)	—	[25]
Leaves	Oxoanolobine	Anticancer activities against human cancer cell lines	Methanol and aqueous	Cytotoxic activity against lung cancer (NCI-H187) cell line (27.60±4.30 μg/mL).	Resazurin microplate assay (REMA), tested with 3 cell lines	Oral cavity cancer (KB), lung cancer (NCI-H187), and breast cancer (MCF-7) cell lines	[13]
Edible plant	Tiliacorinine, tiliacorine, and 2′-nortiliacorinine bisbenzylisoquinoline	Anti-TB	Dichloromethane	3.1μg/ml	MTT assay	MRC-5 cells	[12]

components such as alkaloids, polysaccharides, polyphenolic compounds, fatty acids, and minerals (Table 1).

It was reported that Paris and Sasorith [19] extracted and identified a phytochemical component of *T. triandra*, an alkaloid named tiliacorinine; nevertheless, its chemical structure was not reported. Subsequently, Wiriyachitra and Phuriyakorn [21] also examined root extracts from the plant by thin-layer chromatography and identified four bisbenzylisoquinoline alkaloids, tiliacorinine, nortiliacorinine A, tiliacorine, and tiliacorinine 2′-N-oxide. According to the authors, tiliacorinine and tiliacorine were the main compounds obtained. Likewise, tiliacorinine was the minor polar component, whereas tiliacorinine 2′-N-oxide was the most polar alkaloid. Moreover, the authors determined the absolute configuration of the four compounds through nuclear magnetic resonance (NMR) and biosynthesis experiments. Subsequent studies corroborated that tiliacorinine, nortiliacorinine A, and tiliacorine are the major alkaloids of *T. triandra* roots [12, 18, 20].

Despite the numerous types of research studies on the alkaloids found in *T. triandra* roots, other potentially relevant phytochemical components from the leaves have not received enough attention. Thus, Singthong et al. [22] performed gum extraction from the plant leaves and characterized their physicochemical properties. Their results indicated that the gum contained considerable quantities of proteins, lipids, xylose, glucose, galactose, arabinose, and rhamnose, which might have numerous industrial applications. Likewise, other studies revealed that extracts from *T. triandra* leaves contain saponins, flavonoids, triterpenes, and condensed tannins, which would be associated with the plant's antioxidant activity and other beneficial effects [25–27]. Interestingly, the study conducted by Phadungkit [26] exposed that the leaves extract of *T. triandra* possesses an antimutagenic effect. Thus, Kaewpiboon et al. [2] employed diverse chromatographic techniques like NMR and gas chromatography-mass spectroscopy (GC-MS) to separate and detect the compounds responsible for the anticancer activity. Stearic acid, petroselinic acid, and palmitic acid were identified in the *T. triandra* leaf extract [2]. Remarkably, those fatty acids exhibited chemosensitizer activity. A more comprehensive work indicated that the plant leaf also contains significant amounts of vitamin E, phytol, oleic acid, oleamide, 2-(cyclohexene-1-yl) acetic acid, neophytadiene, 5-hydroxymethyl-2-furancarboxaldehyde, and 2,6-dimethyl-3-(methoxymethyl)-benzoquinone [9]. Moreover, another study accomplished by Rattana et al. [13] identified the alkaloid oxoanolobine as a significant component in the extracts from *T. triandra* leaves. Interestingly, oxoanolobine exhibited potent anticancer activity in a lung cancer cell line (NCI-H187). Similarly, a study conducted by Weerawatanakorn et al. [23] aimed to analyze the polyphenols content of *T. triandra* leaves by HPLC/DAD/MS. Their results indicated that the leaves contain substantial quantities of catechin, chlorophyll A, chlorophyll B, isoquercetin, rutin, tannic acid, and quercetin.

Finally, two very recent studies identified several phytochemical components that had not been reported previously [4, 17]. Makinde et al. [17] analyzed the phytochemical compounds of leaves and twigs of *T. triandra*. Their findings demonstrated six compounds extracted from the plant for the first time (Table 1), including two new fatty acid byproducts. Similarly, the same research group reported the presence of (at least) 18 new compounds [4], which included hexamethylcyclotrisiloxane, pentadecanoic acid, eicosanoic acid, and dibenzyl hydroxylamine, among others (Table 1). Therefore, all these studies highlighted the compounds with numerous biological activities present in the *T. triandra* plant species and warranted further studies to identify more new components for medical and industrial purposes.

5. Pharmacological Properties of *Tiliacora triandra*

T. triandra has been investigated for its pharmacological properties against noncommunicable diseases (e.g., diabetes, cancer, metabolic syndrome, hyperlipidemia, obesity, inflammation, and oxidative disorders) and communicable or infective diseases (those produced by bacteria, parasites, and viruses).

5.1. Effect of Tiliacora triandra on Communicable or Infectious Diseases

5.1.1. Antimicrobial Effects. Multidrug-resistant bacterial strains are the primary causes of infectious diseases worldwide, and it has become a public health problem. Hence, numerous natural products have attracted increasing interest due to their antimicrobial activity and fewer side effects, and research groups focused on identifying bioactive phytochemicals responsible for those properties.

Many studies have explored the antimicrobial properties of various plant extracts, and several herbal formulations are already available against infectious diseases produced by bacteria, fungi, or viruses worldwide. An example of this is the traditional herbal formulation called "*Benchalokawichian*" remedy containing *T. triandra*, popular in Thailand to treat the common cold, fever, and influenza [28]. In this regard, *T. triandra* extracts obtained from *Benchalokawichian* and plant stem barks exhibited effective antimicrobial activity against bacteria such as *Escherichia coli*, *Bacillus cereus*, *Shigella sonnei*, *Acinetobacter baumannii*, *Streptococcus pyogenes*, *Staphylococcus aureus*, *Shigella dysenteriae*, *Bacillus subtilis*, and *Agrobacterium* spp. in *in vitro* assays [25, 28]. The authors reported that the inhibition zones ranged from 11 to 13 mm at the 250 μg/disc concentration, whereas these oscillated from 16 to 21 at 500 μg/disc mm against Gram-positive bacteria. Similarly, the inhibition zones ranged from 13 to 15mm at 250 μg/disc and 17 to 21mm at 500 μg/disc for Gram-negative bacteria. The minimum inhibitory concentration (MIC) fluctuated from 62.5 to 125 μg/mL. Moreover, the extract inhibited the fungus *Aspergillus niger*, *Candida albicans, Trichoderma viride*, *Trichoderma harzianum*, and *Microphamina phaseolina* (inhibition zones from 15 to 22mm, MIC = 62.5–125 μg/mL) [25]. Bioactive compounds such as alkaloids, cardiac glycosides, flavonoids, phenolic compounds, saponins, and

terpenoids were noted to be responsible for the antimicrobial and antifungal properties of the plant extract, i.e., stem of *T. triandra* (Table 2).

Likewise, Sureram et al. [12] reported the antimicrobial potential (by microplate Alamar blue assay) of aerial extracts isolated from *T. triandra* and a chemical derivative against multidrug-resistant *Mycobacterium tuberculosis* strains isolated from extrapulmonary and pulmonary patients (Table 2). The study included numerous isolates with variable resistance to the antibiotics isoniazid, rifampin, ethambutol, streptomycin, and ofloxacin. Their results showed that the bisbenzylisoquinoline alkaloids 2′-nortiliacorinine, tiliacorinine, and tiliacorine (isolated from *T. triandra*) and the derivative 13′-bromo-tiliacorinine exhibited potential antimicrobial effects against 59 clinical strains of multidrug-resistant *M. tuberculosis* with MIC values ranging from 0.7 to 6.2 μg/mL (Table 2) tested in MRC-5 cells using MTT assay. Interestingly, 2′-nortiliacorinine, tiliacorine, and 13′-bromo-tiliacorinine showed more potent activity against the multidrug-resistant isolates than the standard antimicrobial drugs like isoniazid, rifampin, ethambutol, streptomycin, and ofloxacin, suggesting that these compounds would serve as potential new chemical scaffolds for antimycobacterial activity. However, further analyses will be necessary to ensure their specificity and safety profile in human cells.

On the other hand, a similar study by Makinde et al. [3] demonstrated that the ethyl acetate fraction of the leaves, n-hexane, and the ethyl acetate fraction of the twigs exhibited antimicrobial activity against *Staphylococcus aureus* ATCC 25923, *Listeria monocytogenes* F2365, *Escherichia coli* O157:H7, and *Bacillus cereus* (MIC values from 1.5 to 12 mg/mL) [3] with MIC values ranging from 0.39 to 6.25 mg/mL and MBC values ranging from 1.5 to 12 mg/mL compared to antimicrobials like vancomycin, ceftazidime, and penicillin G. Despite the antimicrobial potential of evaluated extracts, no specific phytochemicals were identified in this study; thus, further analyses are required to select the best compounds for optimization.

Concerning the possible antimicrobial mechanisms of action of *T. triandra*, several phytochemicals contained by the plant have shown biological activity against numerous microorganisms. For example, terpenoids, flavonoids, phenolics, saponins, alkaloids, and cardiac glycosides possess antibacterial activity. That activity is possibly due to their capability to complex with bacterial cell walls and to their ability to provoke leakage of proteins and enzymes from cells.

Finally, it is noteworthy that in vitro antimicrobial activities do not always correlate with efficacy in human beings; thus, it will be needed to analyze their effect in animal models before their utilization in humans.

5.1.2. Antiplasmodial Effects. Traditional herbal formulations have been used to treat malaria for a long time; even the most effective allopathic medicines are obtained from plants (quinine and artemisinin). Since other medicinal plants could have antiplasmodial effects, Nutmakul et al. [29] evaluated the potential usefulness of the multiherbal formulation *Benchalokawichian* (BLW), an antipyretic formulation used against malaria like fever that consists of *T. triandra* along with other herbal components. For this purpose, the authors separately extracted constituent plants and compared their efficacy against chloroquine-resistant (W2) and sensitive (D7) strains of *Plasmodium falciparum* by flow cytometry. Furthermore, in order to calculate the selectivity index (SI), they evaluated the toxicity against peripheral blood mononuclear cells through the WST assay.

The BLW exhibited antiplasmodial activity and good SI values ranging from 3.55 to 19.74. In particular, extracts from *T. triandra* showed IC_{50} <5 μg/mL against *Plasmodium falciparum* W2 and 3D7 strains, indicating high antiplasmodial activity compared to camptothecin which was used as a positive control. Likewise, these extracts exhibited SI values >10, suggesting their selectivity and good safety profile.

Subsequently, the authors selected the *T. triandra* extract that presented the higher antiplasmodial effect and SI to isolate their active constituents. They isolated and purified tiliacorinine and yanangcorinine and then explored their antiplasmodial potential and SI. Their results demonstrated that both compounds had good antiplasmodial activity but a low SI separately, indicating that their combination produces a synergistic effect that increases their efficacy and allows their toxicity. Despite promising results, it should be mentioned that these are preliminary data; thus, further preclinical studies are required to unveil the antimalarial potential of *T. triandra*.

5.2. Effect of Tiliacora triandra on Noncommunicable Diseases

5.2.1. Anticancer Effects. The use of carcinoma-derived cell lines in toxicity tests is a method widely accepted to analyze plant extracts' biological and toxic effects. The cytotoxic potential of the water and ethanol extracts of leaves of *T. triandra* against lung cancer cell line (NCI-H187), oral cavity cancer cells (KB), lymphocytes, and HeLa cells has been reported in several studies [9, 13]. One of those studies demonstrated that *T. triandra* extracts exert a dose-dependent cytotoxic effect (0.41 mg/m) on HeLa cells (human cervical carcinoma) viability (50% (IC50)) and lymphocytes isolated from human blood samples [9] (Table 2). The results suggest that *T. triandra* leaf extracts are reasonably safe at the cellular level when equated with untreated cells (negative control) and positive control cells (DMSO treated cells) and incubated with 100 μM of H_2O_2 for 15 min. Compounds, namely, phytol, oleic acid, 1-cyclohexenylacetic acid, oleamide, and vitamin E (α-Tocopherol) were identified as the main phytochemicals responsible for the cytotoxicity and genotoxicity activities of the plant extracts (Table 2).

On the other hand, Rattana et al. [13] evaluated the anticancer activity of *T. triandra* leaves extracts on several human carcinoma cell lines (NCI-H187, oral cavity cancer (KB), and breast cancer cells MCF-7) through in vitro anticancer activity tests, resazurin microplate assay (REMA). Methanol and water extracts exhibited strong activity against NCI-H187 (IC_{50} ranging from 11.93 to 12.27 μg/mL) and KB

(IC_{50} ranging from 12.06 to 32.15 μg/mL) cells (Table 2). The authors concluded that oxoanolobine was the main bioactive compound responsible for these effects and that *T. triandra* might be used to treat and prevent cancer in different cell lines such as oral cavity cancer (KB), lung cancer (NCI-H187), and breast cancer (MCF-7) (Table 2) in comparison to the standard available anticancer drugs like doxorubicin and ellipticine that were used as positive controls in the assays.

On the other hand, it is known that cancer cells possess the capability to develop resistance to drugs, which dramatically reduces the effectiveness of cancer treatments. A key mechanism of this resistance is the increased expression of the P-glycoprotein, a plasma membrane protein that transports numerous anticancer drugs out of the cell. Thus, inhibitors of the P-glycoprotein are of particular medical interest. In this respect, a study suggested that certain constituents of *T. triandra* may act as chemosensitizers on the P-glycoprotein function in the multidrug-resistant A549RT-eto cell lines [2] (Table 2). The subsequent analysis and isolation of components demonstrated that a mixture of three fatty acids, namely, hexadecenoic, octadecanoic, and (z)-6-octadecanoic acids contained by the plant leaves is responsible for the cytotoxic effect against lung cancer even at a concentration of 125 μg/mL determined through MTT assay (Table 2). Etoposide was used as the specific positive control for the A549RT-eto-resistant cells. The M3FA at 125 mg/mL was found to have a clear ability to restore etoposide sensitivity to the A549RT-eto cell line and showed a broadly similar RF value (1.24) to that for F22 at the same concentration (RF=1.30), although this was just over two-fold lower than that for the verapamil control.

5.2.2. Antioxidant Effects. A study on rats has indicated that the extracts of *T. triandra* may enhance the memory deficit in alcoholic rats partly *via* reduced oxidative stress and suppression of acetylcholinesterase (AChE) [5]. The study showed that gallic acid, cyaniding, and quercetin enhance spatial memory at a concentration of 400 mg·kg^{-1}BW, AChE activity in the hippocampus at a concentration of 200mg·kg^{-1}BW, and oxidative stress at 100, 200, and 400mg·kg^{-1}BW determined through CAT, GSH-Px, and SOD activities in male Wistar rats in 7 and 14 days, respectively (Table 2). The study used donepezil (a standard drug for treating memory deficit patients) as a positive control at a concentration of 1mg/kg^{-1}BW. Besides this, another study confirmed the potential antioxidant properties of the *T. triandra* extracts encapsulated with gum Arabic at 10% (w/v) as coating agents [24]. The roughage at a concentrated ratio of 30:70 with *T. triandra* pellets has been reported to serve as a dietary enhancer in male swamp buffaloes [30]. Furthermore, it is known that *T. triandra* is employed in the food industry for its nutritional value [31, 32]. It has also been confirmed that the supplementation of *T. triandra* pellets could enhance feed intake, decrease the protozoa, increase the bacterial population, and increase rumen fermentation efficiency. In contrast, it decreases methane production, thus acting as a good rumen enhancer in beef cattle and buffalos [30, 33].

In 2022, it was reported that *T. triandra* presented protective effects in rats under cisplatin-induced hepatorenal and testicular insults by modulating oxidative inflammation. After four weeks of intragastric administration of *T. triandra* (250 mg/kg) and two weeks of intraperitoneal cisplatin injection (2.5 mg/kg/week), the rats were euthanized to analyze the kidney, liver, testes, and the serum of blood samples. The authors reported that the rats' group treated just with cisplatin presented a higher body weight and lower kidney, liver, and testes weight compared with the control (normal saline) and with the group of *T. triandra* treatment. Meanwhile, the biochemical serum analysis revealed that the *T. triandra* treatment suppressed the increment in some biomarkers related to kidney, liver, and testicular damage such as creatinine, aspartate aminotransferase, luteinizing hormone (LH), and testosterone [34]. The mechanism involves improved sperm count, motility, and viability and ameliorated the reduced serum levels of testosterone, follicle-stimulating hormone (FSH), and luteinizing hormone (LH). It was reported that the phytochemicals phenolic and flavonoids from leaves were able to attenuate cisplatin triggered hepatorenal in cisplatin-injected male Wistar rats within four weeks' time [34] (Table 3). It is crucial to note that the extraction conditions could modify the antioxidant properties of *T. triandra,* and it is vital to evaluate the adequate conditions in terms of the concentration of the molecules [44]. Wungsintaweekul et al. (2018) reported that the root part of Ya-Nang (*T. triandra*) along with other herbs has been used in Thai traditional medicine such as Ya-Ha-Rak or Ben-Ja-Loke-Vi-Chian for relief fever.

5.2.3. Antidiabetic Effects. Makinde et al. [4] recently reported that extracts rich in fatty acids from *T. triandra* leaves and twigs reduced the α-glucosidase activity with IC_{50} values of 11.58–424.06 μM. Dual inhibition of α-amylase and α-glucosidase is linked to gastrointestinal toxic effects like abdominal discomfort, meteorism, flatulence, and diarrhea [45]. Moreover, the *T. triandra* ethyl acetate fraction of leaves and twigs and the n-hexane fractions of twigs strongly inhibited α-glucosidase activity. However, all extract fractions poorly inhibited α-amylase as desired [3]. Additionally, an in vivo study by Makinde et al. [4] indicated that the ethanol extracts of the aerial parts (leaves and twigs) of *T. triandra* at concentrations of 100 and 400 mg/kg markedly increased the insulin level and reduced the fasting blood glucose in streptozotocin-induced diabetic rats after 30 days of inoculation (Table 2). Moreover, *T. triandra* increased the food and water consumption of the treated animals while the body weight decreased. Besides, these extracts decreased total cholesterol and LDL-cholesterol levels, glycosylated hemoglobin (Hb1Ac), transaminases, and alkaline phosphatase. Finally, the extracts improved kidney and liver function; thus, the authors concluded that the plant might be used to treat diabetes and its complications.

In addition, Thong-asa et al. [35] reported that *T. triandra* leaf extracts at 300 and 600mg/kg doses,

Table 3: Premedical and clinical effectiveness of *Tiliacora triandra*.

Plant parts used	Bioactive compound	Positive control/ standard used	Duration of test	Biomedical application	Model tested on/method uses	Possible mechanism	References
Aerial parts	Gallic acid, cyanidin, and quercetin	1,3,3-Tetra ethoxy propane (TEP), H_2O_2	14 days	Brain dysfunction and neurodegeneration	Male Wistar rats	Decreased oxidative stress and the suppression of AChE	[5]
Leaf	Flavonoids	10% Tween 80	4 weeks	Nurture glycemic control and helps against diabetes	High sugar intake mice	Improvement of glucose clearance, inhibition of glycogen breakdown, promotion of glycogen synthesis, inhibition of glucose intestinal absorption, and increased peripheral insulin sensitivity	[35]
Leaves	Phenolic, chlorophyll, alkaloids, and flavonoids	Ascorbic acid, absolute ethanol, tyrosinase, and theophylline	24–72h	Antioxidant and melanogenesis stimulating activities for anti-grey hair treatment	B16F10 melanoma cells	High potential for melanogenesis stimulating activity of the bioactive compounds	[36]
Leaves juice	Calcium	Pandan leaf juice	85h	Rich sources of calcium and antioxidant	30 general consumers	Higher amounts of beta-carotene	[37]
Leaves	p-Hydroxybenzoic acid, minecoside, flavones, glycoside, and cinnamic acids	10% Tween 80	7 days	Enhance memory and hippocampal choline acetyltransferase activity in mice	Male ICR mice (*Mus musculus*) in Morris water maze	Significantly increasing the number of viable cells and mediating the stress-induced neuronal damage through the sympathy-adrenomedullary system and the hypothalamic-pituitary-adrenal system	[16]
Leaves	Phenols and flavonoids	Bilateral common carotid artery occlusion (BLCCAO) +10% Tween 80	37 days	Prevents dentate gyrus neuronal damage in mice	Mice, cognitive tests in the Morris water maze	Enhanced spatial learning and learning flexibility and prevented neuronal death in the DG of mice following ischemia/reperfusion	[15]
Leaves	Tiliacorinine, 20-nortiliacorinine, and tiliacorine	Isoniazid, rifampin, ethambutol, streptomycin, and ofloxacin	8 days	Exhibits antimicrobial activity against multidrug-resistant *Mycobacterium tuberculosis* through bisbenzylisoquinoline	Multidrug-resistant isolates of *M.* tuberculosis through microplate alamarBlue assay and human fetal lung fibroblast cell line	Inhibition of RNA and protein synthesis	[12]
Roots	—	Gentamicin and amphotericin B	48h	Antimicrobial activity against pathogenic strains	*Candida albicans* and methicillin-resistant *Staphylococcus aureus*	—	[28]
Gums	Propionate and butyrate	10% maltodextrin	72h	Probiotics' impact on *Lactobacillus casei* and *L. acidophilus*	*Lactobacillus casei* and *Lactobacillus acidophilus* in vitro colon experiment	Enhanced the accumulation of lactic acid, short-chain fatty acids (SCFA), and beneficial colon bacteria (i.e., lactobacilli and bifidobacteria)	[38]
Stem barks	Phenolics, flavonoids terpenoids, alkaloids, saponins, and cardiac glycosides	Kanamycin and clotrimazole	24–42h	Possess antimicrobial and antifungal activities against multiple strains	*Escherichia coli, Shigella sonnei*, *S. dysenteriae*, *Agrobacterium* spp., and *Aspergillus niger*	Forms complexes with extracellular and soluble proteins as well as bacterial cell walls	[25]

Table 3: Continued.

Plant parts used	Bioactive compound	Positive control/ standard used	Duration of test	Biomedical application	Model tested on/method uses	Possible mechanism	References
Leaves	Thiocyanine, anthocyanins, chlorophyll, and carotenoids	Orlistat	24h	Inhibited pancreatic lipase activity and act as cholesterol-lowering agents	Radioactive cholesterol-treated Caco-2 cells	Inhibition of intestinal cholesterol absorption and lipid digestion and the suppression of cholesterol micellar solubility	[1]
Leaves	Alkaloids and polyphenols	Glibenclamide	8 weeks	Hypoglycemic activities in normal and streptozotocin-induced diabetic rats	Normal and streptozotocin-induced diabetic rats	Stimulating insulin secretion from the pancreas	[39]
Leaves	Tannic acid, gallic acid, and rutin	Dimethylsulfoxide (DMSO)	15min–3h	Anti-inflammatory activity	Murine macrophages RAW 264.7 cells	Downregulated the induction of inflammatory iNOS and COX-2 proteins in LPS-stimulated macrophages	[23]
Leaves	Phenolic and flavonoid	Distilled water	12 weeks	Antihyperglycemic, hyperlipidemia, oxidative stress, and inflammatory conditions in HFD-induced obese mice	High-fat diet (HFD)-induced obese mice	Reduce the malondialdehyde in serum and liver tissue and decrease circulating nonesterified fatty acid and inhibition of hepatic triglyceride synthesis	[40]
Leaves	Hexadecanoic: octadecanoic acid: Z-6-octadecenoic acids	Etoposide	88h	Act as chemosensitizer on polycoprotein function in multidrug-resistant A549RT-eto cell line	MDR human nonsmall-cell lung carcinoma cell line with a high P-gp expression level (A549RT-eto)	Enhanced the relative rate of rhodamine-123 accumulation and reduced P-gp activity	[2]
Leaves	Oxoanolobine	Doxorubicin and ellipticine	48h	Cytotoxic activity against lung cancer (NCI-H187) cell line and oral cavity cancer (KB)	Oral cavity cancer (KB), lung cancer (NCI-H187), and breast cancer (MCF-7) cell lines	--	[13]
Leaves	Vitamin E, phytol, and 1-cyclohexenylacetic acid.	Distilled water and DMSO	48h	Cytotoxicity toward human peripheral blood mononuclear cells (PBMCs) and HeLa cells	Lymphocytes and HeLa cells	--	[9]
Whole plant	Phenolic compounds	DMSO (1%) with PRRSV	76h	Antiporcine reproductive and respiratory syndrome (PRRS) activity	PRRSV propagated MARC-145 tissue	Inhibit PRRSV infection in vitro and replication in MARC-145 cells	[41]
Leaves	Phenolic and flavonoids	Cisplatin and saline water	4 weeks	Attenuation of cisplatin triggered hepatorenal and testicular toxicity	Cisplatin-injected male Wistar rats	Modulating oxidative inflammation, apoptosis, and endocrine deficit	[34]
Leaves	Flavonoids and phenolics	Cisplatin and saline water	5 weeks	Inhibition of CDDP-induced redox-mediated neurotoxicity and behavioral deficit in rats.	Cisplatin-injected male Wistar rats	Abated neurobehavioral deficits, MDA, and cytokine levels and restored CAT, GPx, GSH, SOD, and AChE activities	[42]

Table 3: Continued.

Plant parts used	Bioactive compound	Positive control/ standard used	Duration of test	Biomedical application	Model tested on/method uses	Possible mechanism	References
Leaves and twigs	Gallic acid, cyanidin, quercetin, condense tannin, triterpene, and saponins	Cisplatin and saline water	5 weeks	Antiallodynic and antihyperalgesia activities against cisplatin-induced peripheral neuropathy	Cisplatin-injected male Wistar rats	Significantly restored motor coordination deficits induced by CISP and rats showed marked improvement in thermal/chemical hyperalgesia and mechanical allodynia	[43]

respectively, increased glycogen, whereas reduced blood glucose and serum insulin rates in muscle and liver in mice after administration for four weeks (Table 3). These effects involved an enhancement in glucose clearance, a decrease in glucose intestinal absorption, and an increase in peripheral insulin sensitivity in comparison to high sugar intake mice that were used as a positive control for 4 weeks. The n-hexane extracts of twigs of *T. triandra* were reported to exhibit promising nitric oxide, α-amylase, and α-glucosidase inhibition activities [3]. Furthermore, the leaf extract of this plant also demonstrated hypoglycemia in the mouse model that was fed with a high sugar intake followed by increased glycogen storage in both the liver and muscle and reduced serum insulin level [35]. The therapeutic effect of 5,7-dihydroxy-6-oxoheptadecanoic acid (DHA) extracted from *T. triandra* on rat models of type 2 diabetes mellitus (T2DM) accounted to display a significant increase in fasting blood glucose (FBG), serum lipid profiles, and a reduction in liver antioxidant enzymes such as catalase CAT, superoxide dismutase SOD, and glutathione peroxidase GSH-Px [46]. Besides, Pasachan et al. (56) reported that the aqueous leaf extract of the *T. triandra* inhibited the hepatic glucose production in HepG2 cells and type-2 diabetic rats. Similarly, Song et al. [47] reported the administration of crude ethanol extract of *T. triandra* and its major bioactive compound, DHA, in streptozotocin-induced diabetic Sprague Dawley rats using standard diet fed rats as a positive control (25 and 400mg/kg, respectively) for 30 consecutive days. Authors reported the decrement of urinary protein and albumin levels and the suppression of TNF-α, IL-6 and IL-β after four weeks of both treatments, which secretion is related to NF-κB promotion of oxidative stress in diabetes [47]. The authors used the ethanolic extract of leaves and twigs of *T. triandra* (TTE) and subsequently isolated the best bioactive compound, 5,7-dihydroxy-6-oxoheptadecanoic acid (DHA). Although, in the same extract, they were also able to identify ethyl-5,7-dihydroxy-6-oxooctadecanoate, ethyl pheophorbide A, and pheophorbide A. Interestingly, the authors evaluated TTE at doses of 100 and 400mg/kg, in addition to DHA at a dose of 25mg/kg, with the respective negative controls orally for 30 days. The authors determined that TTE at 400mg/kg and DHA improved diabetic nephropathy, renal and testicular oxidative stress and proinflammation, and reproductive imbalance induced by diabetes, through an improvement in the endogenous antioxidant system, a decrease of lipid peroxidation, and suppression of proinflammation. Although preliminary results are promising, further studies related to the mode of antidiabetic action and the toxicity profile of *T. triandra* extracts are essential. A sufficient amount of information has been gathered for the preclinical antidiabetic potency of *T. triandra.* However, only a clinical trial will guarantee its usefulness in controlling diabetes.

5.2.4. Neuroprotective Effect. Some studies have suggested that *T. triandra* may have a neuroprotective effect, mainly attributed to the antioxidant capacity of the chemicals found in this species. Phunchago et al. [5] evaluated the neuroprotective and cognitive enhancing effects of extracts of the aerial parts of *T. triandra* in ethanol-dependent male Wistar rats. The authors suggested that the *T. triandra* extracts improved the oxidative stress, thus increasing neuron density in the hippocampus, which might be related to the improved memory impairment in ethanol-dependent rats upon 14 days of extract administration at a dose of 100, 200, and 400mg·kg^{-1}BW (Table 3). The results were significantly better than that of the control uses, i.e., the control (without any form of treatment) and the positive controls (ethanol+Aricept/donepezil at a dose of 1mg/kg^{-1}BW and ethanol+vitamin C at dose of 250mg/kg^{-1}BW). The registered components of the extract corresponded to gallic acid, cyanidin, and quercetin in concentrations of 4.81, 307, and 9028μ/100mg of extract. However, the authors also showed other important signals in the chromatograms of the aqueous extract of *T. triandra* that were not considered. Additionally, the global effect observed in memory improvement, increased neuronal density, and oxidative stress could not be differentiated to an extract component, but the authors hypothesized that it could be attributed mainly to quercetin. Subsequent studies could be carried out with the treatment of *T. triandra* extract preventively or after induced ethanol dependence. Similarly, Thong-asa and Bullangpoti [14] tested the neuroprotective potential of the ethanolic extract of *T. triandra* leaves in mice with cerebral ischemic reperfusion injury. Mice exhibited reduced calcium and malondialdehyde, increased antioxidant enzyme activity, and reduced glutathione, superoxide dismutase, and catalase after thirty minutes of BCCAO followed by 45min of reperfusion in mice pretreated with the *T. triandra* extract (300 and 600mg/kg) in contrast to the other combinations tested, such as Sham+10% Tween 80, bilateral common carotid artery occlusion (BCCAO)+10% Tween 80, and Sham+10% Tween 80, and BCCAO+10% Tween 80. The effect of *T. triandra* extracts thus prevents brain oxidative stress, brain infarction, and neurodegeneration in the cerebral cortex and dorsal hippocampus. Furthermore, Thong-asa et al. [15] revealed that leaf extracts of *T. triandra* at a concentration of 300 and 600mg/kg could improve learning flexibility and spatial learning and prevent neuronal death in the mouse model of cerebral ischemia/reperfusion injury (Table 3). The leaf extracts of *T. triandra* are also reported to reduce the etoposide resistance of the A549RT-eto cell lines, which proves the chemosensitizer potential of the *T. triandra* extracts [2]. Several authors have reported the effects of leaf extracts of *T. triandra* on cerebral ischemia/reperfusion injury in mice [15,16]. Huang et al. studied the effect of the antioxidant and anti-inflammatory properties mediated neuroprotective effects of a hydroethanolic extract of *T. triandra* against cisplatin-induced neurotoxicity. They have concluded that the extracts of the *T. triandra*, can reduce the neurotoxicity caused by cisplatin via the improvement of cognitive function and by the integrity linked with the enhanced antioxidant defense mechanism and the antiapoptotic and anti-inflammatory pathways. Furthermore, Thong-asa and Bullangpoti reported the neuroprotective effect of leaves against ischemia-reperfusion in mice by lessening neuronal death and brain infarction in the

hippocampus and cerebral cortex [14]. These findings were further confirmed in another study that verified that *T. triandra* leaf extract at a dose of 300 and 600mg/kg body weight could considerably exhibit neuroprotective effects on hippocampal neurons by increasing the hippocampal choline acetyltransferase (ChAT) activity and total hippocampal cell number in the brain area [16].

In 2021, Liu et al. [43] evaluated the mitigation of peripheral neuropathy triggered by cisplatin in rats using *T. triandra*. The authors found that rats under the *T. triandra* powder treatment restored motor coordination deficits and recovery in thermal and chemical hyperalgesia and mechanical allodynia. Notably, rats presented a significant alteration in hematological parameters generated by cisplatin. However, rats under *T. triandra* treatment (250 and 500mg/kg, po) for 5 weeks showed an increase in white blood cells, platelets, and red blood cells levels, demonstrating the effectiveness of the treatment in amelioration of cisplatin-induced peripheral neuropathic pain in male Wistar rats. These results suggested that the potent antioxidant properties and the ability to reduce inflammation presented by the *T. triandra* power are related to the compounds presented in the employed extract, such as 5,7-dihydroxy-6-oxoheptadecanoic acid, ethyl-5,7-dihydroxy-6-oxooctadecanoate, ethyl linoleate, ethyl linoleate, ethyl pheophorbide A, and pheophorbide A compared to the CISP-treated group for the same duration (2.5mg/kg/week for 4 weeks) and the normal saline-treated rats group [43]. Globally, the literature search supports the neuroprotective efficacy of *T. triandra* in in vitro and animal models. Thus, human trials will likely open a new avenue for its use as a neuroprotective agent.

5.2.5. Antiobesogenic Effect. Some other studies have also evaluated the hypocholesterolemic and antiobesogenic potential of *T. triandra*. A study by Duangjai and Saokaew [1] indicated that methanolic extracts of *T. triandra* leaves at different concentrations (100, 200, 400, and 500 μg/mL) decreased cholesterol uptake by 48% in a Caco-2 cell assay; this effect might be related to the inhibitory capacity of the extracts on pancreatic lipase (IC_{50} = 273.5 μg/mL) (Table 3). Thus, the authors suggested that *T. triandra* might be a potential source of cholesterol-lowering chemicals. *T. triandra* plant extracts at various concentrations (100, 200, 400, and 500 μg/mL) were reported to show promising cholesterol-lowering effects by inhibiting the pancreatic lipase activity (IC_{50} = 273.5 μg/mL) and decreasing the cholesterol micellar solubility [1] when compared with ezetimibe, a cholesterol absorption inhibitor, at 100 μM, which was used as a positive control of cholesterol uptake in *in vitro* experiments (Table 3). It was also reported that the inhibition potential of *T. triandra* extracts (273.5 μg/mL) for pancreatic lipase activity is less potent than orlistat (IC_{50} at 1.52 ng/mL), a well-known pancreatic lipase inhibitor, which prevents dietary fat from being absorbed in the intestine. A possible limitation of this study is that there is no detailed description of the pharmacological effect according to the composition of the extract. The authors hypothesize that anthocyanins decrease the micellar cholesterol solubility and then suppress cholesterol uptake in Caco-2 cells. Also, the authors suggest that phenolic compounds modulate the size and solubility of cholesterol micelles and inhibitory cholesterol uptake. However, this phenomenon would seem to be dose-dependent and related to the type of chemical composition. The antiobesogenic potential of *T. triandra* in terms of inhibiting pancreatic lipase, enrichment of lipolysis, and reduction of lipid accretion was reported by Ruangaram and Kato [48]. A compound in *T. triandra* (tiliacorinine 12′-O-acetate) was studied for its vasorelaxation properties and its mechanism in isolated rat aorta [49]. Tiliacorinine is one of the main constituents of *T. triandra* with a moderate vasorelaxant effect. However, the acetylation of tiliacorinine and tiliacorinine 12′-O-acetate exhibited higher vasorelaxant activity. The mechanism elucidated by the authors confirms that tiliacorinine 12′-O-acetate induced endothelium-dependent vasorelaxation through the eNOS/NO/sGC pathway in rat aorta and also induced endothelium-independent vasorelaxation involving the modulation of sGC activity, Kv channels, and Ca^{2+} influx through Ca^{2+} channels and intracellular Ca^{2+} release on smooth muscle cells. Last, *T. triandra* alleviates hyperglycemia, hyperlipidemia, oxidative stress, and inflammation properties in obese conditions induced by a high-fat diet in rats [40]. The studies regarding the effect of *T. triandra* on noncommunicable diseases are still not definitive. Many studies are still needed, among them are the toxicological and pharmacokinetic studies identifying and isolating the compound or compounds responsible for the potential clinical effect and testing their administration mode. Moreover, the mechanism of action of *T. triandra* extracts is still not elucidated.

5.2.6. Miscellaneous Properties. While numerous works of literature established *T. triandra* as an important traditional plant with multiple beneficial effects, research using animal models has further confirmed their roles against different forms of health ailments. Studies support the antiallergic potency of *Benchalokawichian* (BCW) on itching and treatment of other skin allergic disorders [50]. *T. triandra* extracts significantly reduced porcine reproductive and respiratory syndrome, PRRS (derived high burden on the swine industry in the world) virus infectivity in MARC-145 cells, and virus titer 3.5 median, tissue culture infective dose (TCID50)/ml (log10) at 24h postinfection. Authors suggested that *T. triandra* could suitably prevent porcine reproductive and respiratory syndrome (PRRS) caused by the PRRS virus in pigs under the in vivo condition [41]. Their results showed that the extract from the *T. triandra* significantly inhibited the infection of the PRRS virus in the MARC-145 cells at an effective dose of 2.5 $TCID_{50}$/ml (log 10) after 72h of postinfection [41]. However, its use is pending on further validation of *T. triandra* efficacy in pigs infected with PRRS. In another study, Duangjai and Saokaew [1] indicated that the leaf extracts of *T. triandra* decreased cholesterol uptake by up to 48% in a Caco-2 cell model. Another study revealed that leaves act in mice with ischemia/reperfusion injury to support memory and behavioral flexibility [15]. Lupeol in the extracts of *Ha-Rak* (a

combination of plants including that of *T. triandra*) showing cytotoxicity against SW620 cell lines with the IC_{50} values of 30.10–212.24 μg/ml was reported by Somwong and Chuchote [51].

Usage of supplements of bamboo grass (*T. triandra*) is known to improve feed intake, digestibility of nutrients, especially roughage intake, and digestibility of dry matter and neutral dietary fiber in dairy cows without any adverse effects on milk production or quality. Such activities were mainly due to bioactive compounds such as condensed tannins and propionic acid [52]. The authors supported their explanation with the effect produced by condensed tannins (CT). CT binds with dietary proteins and delays protein degradation, increasing protein utilization for microbial protein synthesis and feeding digestion. However, the authors did not determine the structural composition of the *T. triandra* pellet, so further studies would be attractive to establish a more precise correlation. Furthermore, the *T. triandra* supplementation significantly increased the concentration of certain unsaturated fatty acids, such as linoleic conjugates. Overall, *T. triandra* possesses numerous potential bioactive compounds that can be safely used in humans soon through modern-day clinical research. Some of the critical biomedical applications of *T. triandra* are listed (Table 3).

6. Future Perspective of *T. triandra* in Medication and Nutrition

From the above discussion, it can be speculated that the extracts of *T. triandra* possess several nutritional values and potential for treatment against infectious diseases. While several researchers have only focused on the isolation of novel bioactive compounds with multiple applications in the biomedical field, the nutritional potential of the plant has dramatically been overlooked [53]. Although the plant possesses numerous biological activities and may be effective as a source of different drugs, the in-depth in vivo analysis, mechanism of action, and elucidation of the potential pharmacological properties require further investigation. Its pharmacological efficacy could be enhanced by applying modern scientific tools, including nanotechnology and advanced drug delivery systems. Since the scanty information on the in vivo and clinical experimental data, further detailed research must be undertaken to analyze and quantify the benefits of *T. triandra* extracts as a potential source of modern-day drugs and as a nutritional supplement for humans and animals. Recent advancements and developments in drug discovery and delivery systems have indicated that nanoparticles synthesized from diverse sources of plant-based materials tend to display improved biomedical or pharmacological activity in comparison to the crude source of plant material [17,36]. Therefore, future research must focus on the green synthesis of various metallic, zero-valent nanoparticles using the extracts of *T. triandra* as the source of reducing agents in the synthesis process and study its biomedical applications.

7. Conclusions

T. triandra plant species are rich sources of bioactive compounds like alkaloids, flavonoids, terpenoids, proteins, and carbohydrates. Based on its numerous ethnomedicinal potentials, this plant species could also be used as a source of nutraceuticals. Moreover, it possesses antimicrobial, antiparasitic, antidiabetic, anticancer, antioxidant, and anti-obesogenic activities. It is an underappreciated species with several potential uses in traditional herbal therapy. The vast nutritional properties of these plant species need further in-depth investigation for their effective applications in pharmaceutical and biomedical fields. Therefore, further advanced research must be directed toward the in vitro and in vivo investigations of the *T. triandra* plant species for verifying its medicinal properties against several infectious and noninfectious diseases and its utility as a novel nutritional supplement.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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