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REVIEW ARTICLE

Phytochemical and pharmacological advancement on *Tridax procumbens* L.: A traditional medicinal plant with multiple health benefits: A review

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Abstract

Tridax procumbens L. is a persistent herb typically found as an agronomic weed that grows on wasteland or invades bare soil. Indigenous medicine has employed several extracts of *T. procumbens* to treat an array of illnesses in both humans and animals. The primary objective of this study is to comprehensively review the phytochemical constituents and medicinal potential of *T. procumbens*, highlighting its traditional and pharmacological uses with updated literature. The study aims to consolidate scientific literature on *T. procumbens*, its biological activities and therapeutic applications to provide a valuable ethnomedicinal reference. Despite the traditional and ethnomedicinal significance of *T. procumbens*, several critical research gaps remain, including a lack of in-depth phytochemical characterization. Bridging these gaps is essential for advancing *T. procumbens* from traditional use to evidence-based therapeutic applications. The literature review confirms the presence of several crucial phytochemicals in *T. procumbens* such as alkaloids, tannins, flavonoids, phenols, proteins, anthocyanins and amino acids. These compounds are associated with various biological activities including wound healing, antioxidant and antibacterial effects, anti-inflammatory properties, antifungal, antiparasitic, insecticidal and immunomodulatory therapeutic effects. *Tridax procumbens* demonstrates significant potential as a medicinal plant with a broad range of biological activities attributed to its diverse phytochemical profile. However, further in-depth pharmacological studies, clinical investigations and toxicological assessments are essential to validate its ethnomedicinal claims and develop it into a reliable therapeutic agent. This review underscores the need for advanced research to bridge the gap between traditional knowledge and modern evidence-based medicine.

Keywords: ethnomedicinal; pharmacological; phytochemical; medicinal plant; *Tridax procumbens*

Introduction

Nature has generously provided us with various therapeutic plants from which many contemporary medications have already been extracted (1). According to World Health Organization (WHO), over 80 % of people practice some form of traditional medicine and herbal medicine for their basic well-being (2). Since pre-Hispanic times, indigenous doctors have utilized medicinal plants, which are a part of human traditional practice (3). Plant secondary metabolites with pharmacological qualities are helpful; some are essential drug components for antitumor, antivirals, antiepileptics, antibiotics and more (4, 5).

The *Tridax procumbens* is also recognized as "coat buttons," a perennial plant belonging to the family Asteraceae, indigenous to South and Central America (6, 7). *Tridax* species have been utilized in Indian Ayurveda since ancient times (8). *Tridax procumbens* are found throughout India, especially in Maharashtra, Madhya Pradesh, Chhattisgarh, Tamil Nadu, Kerala, Rajasthan and Uttar Pradesh and more regions as a weed. *Tridax procumbens* has various pharmacological properties like antimicrobial, immunomodulatory, antioxidant, antidiabetic, analgesic and antifungal activities (9).

Developed and developing nations frequently employ herbal remedies or traditional medicines to treat various illnesses. Synthetic medication side effects account for 8 % hospital admissions in the USA and these toxicities cause around 100000 deaths annually (9, 10). Therefore, natural medications that minimise synthetic side effects and toxicities and simultaneously increase therapeutic potential to cure various diseases are increasingly being explored. The key objective of this study is to comprehensively review the phytochemical constituents and medicinal potential of *T. procumbens* and highlight its traditional and pharmacological uses with updated literature. Few manuscripts have been published in *T. procumbens* related to phytochemicals and pharmacological activity; however, the present review covers all aspects of the plant's biological activity with updated information. This review bridges the gap between traditional knowledge and

modern evidence-based medicine. Finally, this review provides significant information on this species. It specifies phytochemicals for specific treatments for safe and low-cost treatment of some ailments, especially in tropical and sub-tropical areas. The taxonomical classification of T. procumbens is presented below to provide systematic and botanical details of the species (11).

Taxonomical classification of *T. procumbens*

Kingdom	:	Plantae
Phylum	:	Streptophyta
Class	:	Equisetopsida
Subclass	:	Magnoliidae
Order	:	Asterales
Family	:	Asteraceae
Genus	:	*Tridax*
Species	:	*procumbens*

Distribution

The *T. procumbens* belongs to the family Asteraceae, native to Central and South America and is an extensively distributed herb that generally grows like grass (12). This genus includes about 26 species (13). *Tridax procumbens* mainly originated in Central America but now can be found throughout the tropical and subtropical areas of the world growing with annual crops, along roadsides, pastures, fallow land, dikes, railroads, riverbanks, meadows, dunes and waste areas (9). *Tridax procumbens* is perennial, blossoming and producing fruit usually named in Hindi 'Ghamra', in English 'Wild daisy' and 'Coat buttons' and in Sanskrit as 'Jayanti-veda' based on the presence of the flower (14) (Table 1 & Fig. 1). *Tridax procumbens* is extensively spread in India and this plant thrives in various soil types, including dry and moist conditions (12, 15).

Traditional and ethnomedicinal applications

Coat Button (*T. procumbens*) has been used in folk remedies and practices for various health benefits. The multiple studies highlight the widespread use of Coat Button in traditional medicine, which suggests it may hold promise as a potential analgesic agent (19). The plant is prevalent throughout India and is utilised in indigenous medicine for various ailments. In Ayurvedic medicine, it is widely used due to its medicinal properties, including reducing blood pressure, bronchial catarrh, malaria, dysentery, diarrhoea, stomach-ache, wound healing, headaches and preventing hair loss and haemorrhage from cuts and bruises (19). This versatile herb has also been associated with treating various diseases, including malaria, leishmaniasis and dysentery. Up-to-date recent research studies have noted that lactating pregnant women in Chiquimula, Guatemala, suffering from anemia could alleviate their symptoms by using *T. procumbens* (6). Aqueous extracts of Coat Button exhibit significant activity against *Trypanosoma brucei*, along with antibacterial and wound-healing properties (20). The flowers and leaves possess antiseptic, insecticidal and parasiticidal properties and the plant exhibits various pharmacological activities such as immunomodulatory, antidiabetic, antihepatotoxic, antioxidant, anti-inflammatory, analgesic, anticancer and marked depressant action on respiration (21). It plays a crucial role in defluoridation water, providing an inexpensive method in regions where the natural level of fluoride minerals is high in groundwater (22).

Typhoid fever, cough, fever, backache, diarrhoea and epilepsy are treated with the entire plant of *T. procumbens* in Nigeria; besides, this plant is used by African farmers to treat livestock (6). A study in Tamil Nadu, India, revealed that native inhabitants apply the leaf juice to heal wounds. In Udaipur in Rajasthan, India, people traditionally consume powdered *T. procumbens* leaves mixed with other herbs to manage diabetes. In some other parts of the world, traditional healers and local communities also use the leaves of this plant as a treatment for conjunctivitis (9).

Phytochemical screening

Phytochemicals are chemical compounds naturally present in plants and are credited with positive or adverse health effects (23). Phytochemical screening identifies and analyses the chemical compounds or phytochemicals, present in plant extracts (24). These compounds, often secondary metabolites, can be investigated for their potential medicinal or biological activities. The screening involves various qualitative and quantitative tests to detect the presence and estimate the amounts of different phytochemicals (25). The phytochemical components of the plants have healing qualities (26). Flavonoids, alkaloids, tannins, phenolics, steroids, saponins, terpenes, glycosides and other vital phytochemicals are found in different plant parts. Besides, fatty acid derivatives, lipid constituents—luteolin, glucoluteolin and quercetin are described (27, 28). In *T. procumbens*, diverse phytochemicals were reported

Table 1. List of common names of *Tridax procumbens* throughout the world

Country/region	Common names	References
English	Coat buttons, Tridax daisy	(7, 16)
Chinese	Kotobukigiku	
Sanskrit	Kumminnippacha	
Latin	*Tridax procumbens*	
Kannada	Jayanthi	
Japanese	Kotobukigiku	
Spanish	Cadillochisaca	
Gujrati	Ghaburi	
Telegu	Gaddi chemanthi	
Tamil	Thatapoodu	
United States	*Tridax* daisy	(9)
Assamese	Bikhalyakarani	
Hindi	Ghamra	
Bengali	Tridhara	
Oriya	Bishalyakarani	
Malayalam	Chiravanak	
French	Herbecailli	
Marathi	Kambarmodi, Jakhamjudi and Tantani	
Thai	Tintúkkæ	
Nigeria	Igbalobe, muwagun, muriyampachila, jayanti, vettukkaaya-thala	(17)
Guatemala	Bull grass, bull's herb	(18)

Fig. 1. Morphology of Leaves, bud, flower and stem of *Tridax procumbens.*

Table 2. Different solvent extraction using different parts of *Tridax procumbens*

Extraction	Plant part	Compounds	References
Chloroform extract and Chloroform water extract	Leaves	Steroid, saponin, coumarins, alkaloids, amino acids, diterpenes, phenol and flavonoids, amino acids, phlobatannin	
Acetone-water extract and acetone extract	Leaves	Steroid, tannin, saponin, anthocyanin, coumarins, alkaloids, diterpenes, phenol and flavonoids, proteins, carbohydrate, antioxidant property	
Aqueous extract	Leaves	Blood clotting properties	(9)
Acetone extracts	Roots, leaves	Antibacterial activity	
Methanol extract	Leaves	Alkaloids, tannin, anthocyanins, proteins, saponin, steroid, phlobatannin, terpenoids, flavonoids, amino acids, phenols and cardiac glycosides, antibacterial activity, antioxidant properties	(29)
Ethanol extract	Whole plant	Flavonoid, quercitin, alkaloids, tannins, flavonoids, saponins and phenolic compounds	(30)
Petroleum ether and ethanolic extract	Whole plant	Antibacterial activity against *B. faecalis* due to presence of alkaloids, tannins, steroids, purines, carbohydrates, proteins	(31)
Chloroform extract	Whole plant	Against *B. faecalis* and *E. coli*	
Aqueous extract	Leaves	DPPH radical scavenging activity	(32)
Ethanol extract	Leaves	Polyphenol content, flavonoids, antibacterial activity against *Pseudomonas aeruginosa*	(32, 33)
Methanol extract fractioned with Dichloromethane (DCM)	Aerial parts of plant	9, 12-octadecadienoic acid ethyl ester (18.04 %), 5-cholestane (12.42 %), hexadecanoic acid ethyl ester (4.86 %) and 9-octadecenoic acid ethyl ester (4.72 %). Cholestane glycosides and rhamnosides are known for their potent cytotoxicity against malignant tumor cells.	(34)

from different parts of the plants with various biological activities (Table 2).

Flavonoids

Flavonoids are a large group of naturally occurring plant compounds in the polyphenol class. It can be detected by the Alkaline reagent test, NH_4OH test, Mg turning test and Zn test (35). Flavonoids constitute a major and repeatedly reported class in *T. procumbens*. A novel flavonoid glycoside named procumbenetin (3,6-dimethoxy-5,7,2′,3′,4′-pentahydroxyflavone 7-O-β-D glucopyranoside) was isolated and fully characterised from aerial parts, an essential structural finding that demonstrates the plant's unique flavonoid profile. Other flavonoids reported in various surveys include apigenin, quercetin, luteolin and related derivatives. These polyphenolic molecules are frequently linked to antioxidant and anti-inflammatory properties (36, 37).

Alkaloids

Alkaloids are a large group of naturally occurring nitrogen-containing organic compounds that plants produce as secondary

metabolites. Dragendroff's, Mayer, Wagner and Hager's tests were used to detect alkaloids (35). Alkaloids have been reported in aqueous, ethanolic, methanolic and chloroform extracts of leaves, stems and flowers, confirmed their presence in both aqueous and ethanolic extracts of leaves and identified nitrogen-containing peaks in GC-MS profiles of methanolic extracts, suggestive of heterocyclic alkaloids (38, 39). Alkaloids may contribute to the plant's antimicrobial and wound-healing activities.

Tannins

Tannins are a group of naturally occurring polyphenolic compounds found in many plants. The Lead acetate [$Pb(CH_3COO)_2$] and Iron(III) chloride [$FeCl_3$] (5 %) test can detect it (35). Tannins are consistently reported in qualitative screenings of *T. procumbens* leaves, stems and flowers. Tannins exhibit antibacterial and antifungal properties, enhancing the plant's traditional medicinal use in treating infections. They also help scavenge free radicals, thereby protecting cells from oxidative damage and may reduce inflammation, supporting their role in wound healing and the management of various inflammatory conditions (40) (Table 3 & Fig. 2a , b).

Terpenoids

Terpenoids (also called isoprenoids) are a large and diverse group of naturally occurring organic compounds which can be detected by mixing about 5 mL of each extract in 2 mL of chloroform and adding 3 mL of concentrated H_2SO_4, which forms a reddish-brown precipitate indicator (41). Pentacyclic triterpenes such as lupeol, oleanolic acid and taraxasteryl acetate have been isolated from *T. procumbens*. Terpenoids are also detected in preliminary phytochemical screenings of methanolic, ethanolic and hexane extracts. These compounds have been linked to anti-inflammatory, hepatoprotective and antimicrobial effects (42).

Saponins

Saponins are a group of naturally occurring plant compounds known for their soap-like properties. It can be detected by the Foam Test and the Haemolysis Test (35). Saponins have been detected in leaves and whole plants' aqueous, methanolic and ethanolic extracts. These glycosides possess surfactant properties and contribute to antimicrobial and anti-inflammatory actions. Their foaming ability in aqueous extracts is a typical qualitative test result for *T. procumbens* (43).

Phenolic Compounds

Phenolic compounds are a large and diverse group of plant chemicals (phytochemicals) that have one or more phenol groups in their structure, which can be detected by the formation of intense colour on the addition of 0.5 mL of $FeCl_3$ (w/v) solution into 2 mL of test solution, indicating the presence of phenols (44). Phenolics, including simple phenols and complex polyphenols, are abundant in *T. procumbens* extracts. They are major contributors to the plant's antioxidant potential. Quantitative assays such as the Folin–Ciocalteu method have shown significant phenolic content, with flavonoids making up a large proportion. Phenolic compounds act synergistically with flavonoids and tannins to provide free radical scavenging and anti-inflammatory effects (45) (Table 3 & Fig. 2a, b).

Pharmacological activity

The therapeutic potential of the various solvent extracts of *T. procumbens* has been thoroughly investigated for their antifungal, antibacterial, immunomodulatory, wound healing, anticancer, antioxidant, larvicidal, anticoagulating, homeostatic activities and more (Fig. 3). This review discuss the pharmacological properties of *T. procumbens* extracts and their metabolites both *in vitro* and *in vivo* (Table 4 & Fig. 3).

Anti-bacterial activity

Table 3. List of different phytochemicals detected in *Tridax procumbens* and their activity

Sl. No.	Phytochemical	Compounds	Mol. formula	Pharmacological Activity	References
1.	Alkaloid	Tryptanthrin	$C_{15}H_{18}N_2O_2$	Anticancer, antimicrobial, anti-inflammatory, antioxidant.	(46, 47)
		BetulinicAcid	$C_{30}H_{48}O_3$	Anticancer, anti-inflammatory, hepatoprotective, antioxidant	(48, 49)
		Stigmasterol	$C_{29}H_{48}O$	Anti-inflammatory, hypocholesterolemic, antidiabetic, antioxidant, anticancer.	(50, 51)
2.	Flavonoids	Quercetin	$C_{15}H_{10}O_7$	Potent antioxidant, anti-inflammatory, anticancer, cardioprotective, neuroprotective, antihypertensive.	(52, 53)
		Luteolin	$C_{15}H_{10}O_6$	Antioxidant, anti-inflammatory, anticancer, neuroprotective, analgesic/ antiallergen	(54, 55)
		Catechin	$C_{15}H_{14}O_6$	Antioxidant/free-radical scavenger, cardioprotective, anti-inflammatory, antimicrobial, anti-cancer	(56, 57)
		Kaempferol	$C_{15}H_{10}O_6$	Antioxidant, anti-inflammatory, anticancer, neuroprotective, hepatoprotective, antidiabetic	(58, 59)
		Apigenin	$C_{15}H_{10}O_5$	Antioxidant, anti-inflammatory, anticancer, neuroprotective, anxiolytic/ sedative properties	(60, 61)
3.	Tannins	Ellagic acid	$C_{14}H_6O_8$	Antioxidant, anti-inflammatory, antimutagenic/anticancer, hepatoprotective, cardioprotective, neuroprotective.	(37, 62)
		Gallicacid	$C_7H_6O_5$	Antioxidant, anti-inflammatory, antimicrobial, anticancer, neuroprotective, hepatoprotective.	(63, 64)
4.	Terpenoids	Eugenol	$C_{10}H_{12}O_2$	Antioxidant, anti-inflammatory	(65)
5.	Saponins	Disogenin	$C_{27}H_{42}O_3$	Anticancer/antiproliferative, anti-inflammatory, hypolipidemic, antidiabetic, osteoprotective, cardioprotective.	(66, 67)
		Oleanolicacid	$C_{30}H_{48}O_3$	Hepatoprotective, anti-inflammatory, antioxidant, anticancer, antiviral, cardioprotective, hypoglycemic	(68, 69)
		Hederagenin	$C_{30}H_{48}O_4$	Anti-inflammatory, antimicrobial, anticancer, neuroprotective, metabolic benefits	(70)
		Campesterol	$C_{28}H_{48}O$	Phytosterol- cholesterol-lowering (reduces intestinal cholesterol uptake), anti-inflammatory, antioxidant, potential chemopreventive effects	(71)
6.	Phenolic Compound	Caffeicacid	$C_9H_8O_4$	Antioxidant, anti-inflammatory, anticancer (modulates signalling), antiviral/ antimicrobial, neuro- and hepatoprotective.	(72, 73)
		Chlorogenicacid	$C_{16}H_{18}O_9$	Antioxidant, anti-inflammatory, hepatoprotective, cardioprotective, antidiabetic (glucose-metabolism modulating), neuroprotective, antimicrobial	(74, 75)
		Ferulic acid	$C_{10}H_{10}O_4$	Antioxidant, anti-inflammatory, neuroprotective, cardioprotective/ antithrombotic, anticancer (chemo-preventive), skin-protective	(37, 76)

Table 4. Different phytochemicals in different parts of *Tridax procumbens* and their biological activity

Activity	Part used	Solvent	Phytochemical	Reference
Anti inflammatory	Aerial parts	Ethanol	Cent aureidin, Centaurein and Bergenin Luteolin-4'-O-B-D-glucopyranoside	(77)
Anti-bacterial	Aerial part	Ethanol	3-0-methylquercetin-4'-O-β-D-glucopyranoside 3-0-methylquercetin-4'-O-β-D-glucopyranoside	(78, 79)
Anti-fungal			S 8,3 -dihydroxy-3,7,4 -trimethoxy-6-O-ˇ-d-glucopyranosyl flavones, 6,8,3 -trihydroxy-3,7,4 -trimethoxyflavone, puerarin, esculetin, oleanolic acid, betulinic acid, centaurein, bergenin and centaureidin	(34)
Anti-cancer	Aerial part	Ethanol	(3S,5R,6S,7E)- 5,6 epoxy 3-hydroxy-7-megastigmene-9-one Icaricide B1	(78, 80)
Anti leishmanial	Leaves	Methanol	(3S)-16-17-Didehydrofalcarinol or Oxylipin R= Gu 8,3'-dihydroxy-3,7,4'-trimethoxy-6-O-B-D glucopyranosyl flavone	(78, 81)
Anti-oxidant	Aerial parts	Ethanol	Queracetangatin- 3, 6-4'-trihydroxy-7-O-neohesperidoside 3-0-methylquercetin-4'-O-B-D-glucopyranoside	(78)
Wound healing			Queracetangatin- 3, 6-4'-trihydroxy-7-O-β-D-glucopyranoside Caffeic acid, Epicatechin, Kaempferol and Tannic acid,	(72)

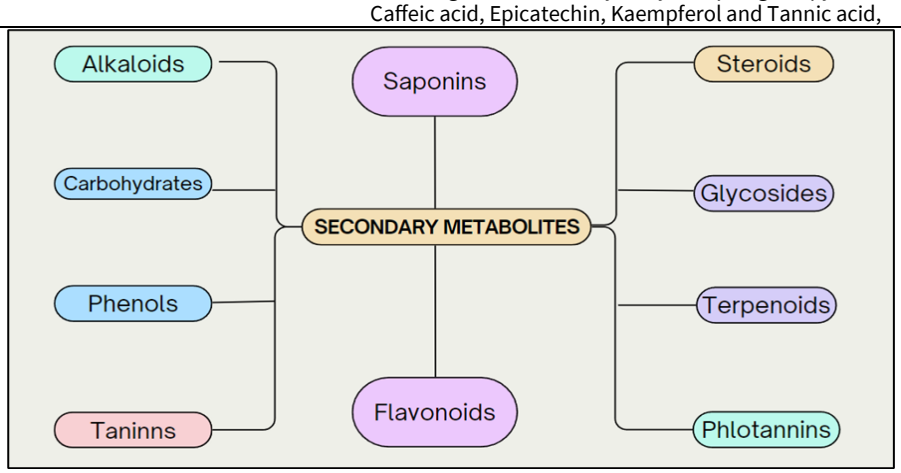

Fig. 2a. Different secondary metabolites present in *Tridax procumbens* extracts.

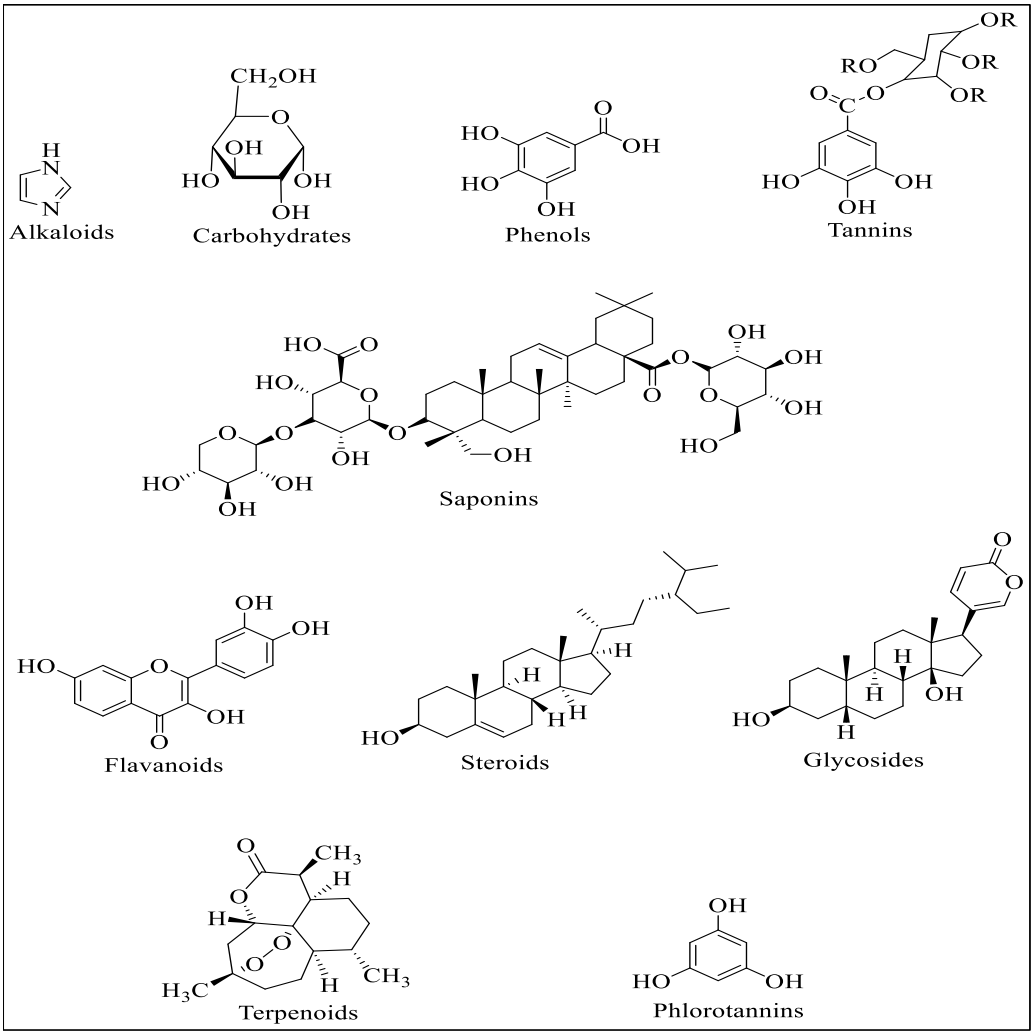

Fig. 2b. Elucidation of secondary metabolites from *Tridax procumbens*.

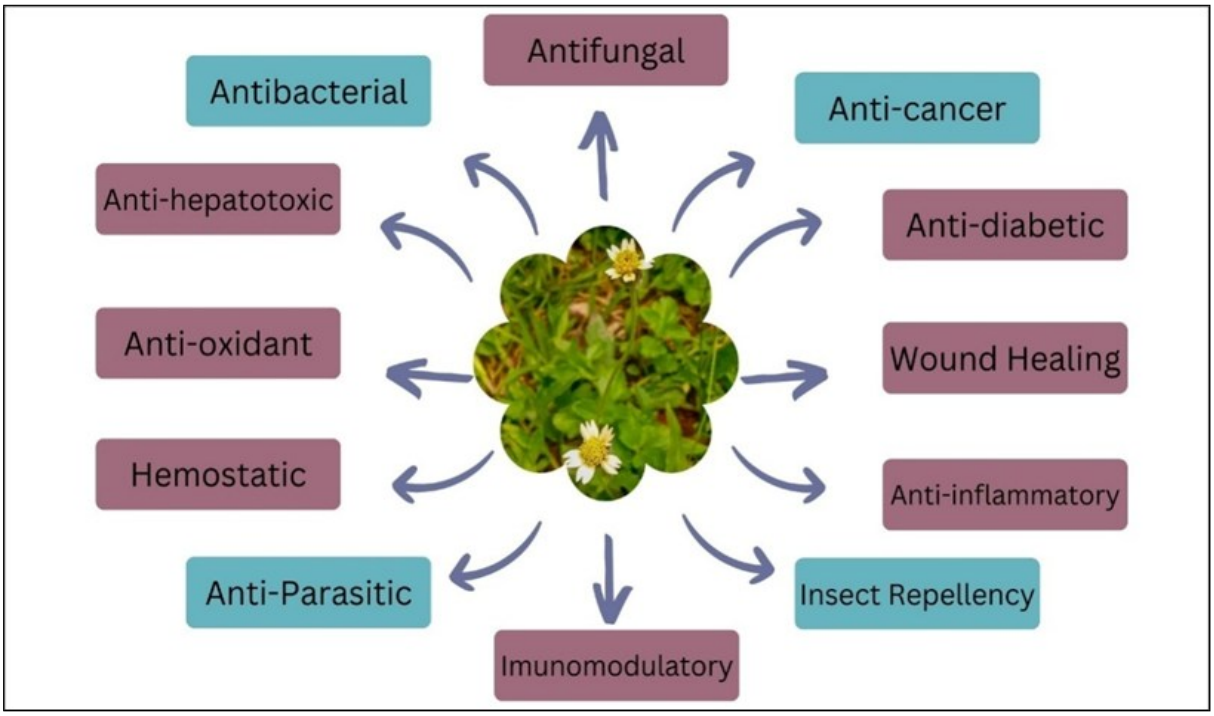

Fig. 3. Pharmacological activity of *Tridax procumbens* extracts.

The antibacterial assay of *T. procumbens'* various solvent extracts against different bacterial species was tested using disc diffusion and well diffusion methods. Disc diffusion technique revealed that *T. procumbens* methanolic extract showed a zone of inhibition (ZOI) in *Escherichia coli.* However, the ethyl acetate extract demonstrated a larger ZOI in *Bacillus cereus, Staphylococcus aureus* and *Salmonella typhi* (82). For *Pseudomonas vulgaris,* ethyl alcohol extract of *T. procumbens* leaf is the most potent antibacterial agent (9). Tannins and flavonoids with multiple mechanisms of action, including inhibition of cytoplasmic membrane function, energy metabolism and DNA gyrase, further ethanolic extract demonstrated antibacterial activity against multidrug-resistant *Pseudomonas* from nosocomial infections (33, 83, 84).

Tridax procumbens ethanolic extract displayed antibacterial action on nosocomial strain of *Pseudomonas aeruginosa* from pneumonia patient secretions, including bronchoalveolar lavage and tracheal secretions (33). Further, the methanolic extract of *T. procumbens* flower was found to inhibit *P. aeruginosa*, *E. coli* and *B. cereus*. In contrast, the methanolic extract of the leaf demonstrated the maximum zone against *Pseudomonas fluorescens* (85). In addition, the extract of *T. procumbens* leaf with methanol, ethanol and ethyl acetate against *Bacillus subtilis, Enterobacter aerogenes, S. aureus* and *E. coli* showed good activity (86).

Four bacterial strains, *Proteus mirabilis*, *B. subtilis, S. aureus* and *E. coli* were tested against various *T. procumbens* extracts. The ethyl acetate extract had the most excellent potent repressing effects on all the tested strains of bacteria. Meanwhile, hexane extract inhibits *S. aureus* and *E. coli*, while chloroform extract only inhibits *S. aureus* (87). Ethanolic extract of *T. procumbens* at 200 mg/mL demonstrated broad-spectrum activities on every tested bacterium; *E. coli* had the least inhibitory effect, while *S. aureus* had the maximum inhibition (88).

Petroleum ether, hexane extracts of *T. procumbens* leaf, flower and stem showed antibacterial efficacy against gram-negative (*E. aerogenes*) and gram-positive (*S. aureus* and *B. subtilis)* bacteria. However, the flower's hexane extract showed potent antibacterial activity against *E. aerogenes*, with a 20 mm zone of inhibition. The test bacteria were moderately inhibited by the leaf, followed by the stem. Petroleum ether had a moderate effect on the test bacteria, while chloroform extracts were found to be the least active (86). Furthermore, aqueous extract of *T. procumbens* was used to test the antibacterial assay against *E. coli, Enterococcus faecalis, B. subtilis* and *P. aeruginosa* (89). Studies on *T. procumbens* different plant parts with different solvents demonstrated that extracts have rich active phytochemicals that can suppress the microbes by static and cidal action (Table 4 & Fig. 3).

Anti-fungal activity

The *T. procumbens* can control fungal growth from the presence of phenols, flavonoids, saponins, sterols and fatty acids (9, 90). Significant inhibitory action against *Candida albicans* was demonstrated by *T. procumbens* methanol extract from various leaves, stems, flower and roots, showing 8-13 mm inhibition. Additionally, root methanol extract demonstrated intense action against *Candida tropicalis* and *Candida glabrata*, indicating that *T. procumbens* bioactive components could be employed as potent anti-candidal medications (91).

The *T. procumbens* showed activity against both *Aspergillus turcosus* and *Aspergillus parasiticus.* Significant inhibition zone was observed in ethanol, aqueous, chloroform and methanol extracts at different concentration range between 1 to 5 mg/mL; however, the highest inhibition was observed in aqueous and chloroform extracts (20 mm at 5 mg/mL) against *A. parasiticus* (92). *Curvularia eragrostidis* was less effective than *Bipolaris sorokiniana* when treated with *T. procumbens* aqueous alcohol extract (93). Further, *T. procumbens* ethanolic extract showed maximum antifungal activity towards *A. flavus* and *C. albicans* (94).

The *T. procumbens* methanolic extract on *A. fumigatus*, A.niger, *C. albicans* inhibition range was 9–15 mm (82). Additionally, in comparison to ciprofloxacin, *T. procumbens* methanolic extracts

demonstrated efficient suppression against *A. niger* and *A. ocraceous* (95). Furthermore, *T. procumbens* methanolic leaf extract at 0.1 % and 0.01 % concentrations was tested against *Helminthosporium oryzae, Rhizoctonia solani* and *Pyricularia oryzae* at 0.1 % and 0.01 % concentrations; the comparative magnitude of percent inhibition was found to be higher in *H. oryzae* and *R. solani* than in the other two pathogens over their respective controls (96).

Anti-hepatotoxic or hepatoprotective activity

An antihepatotoxic agent protects the liver from damage and can prevent or reduce the damaging effects of toxins and diseases on the liver. The alcoholic extract of *T. procumbens* triggers the cholinergic receptors, which protect the liver through the vagus nerve; furthermore, this extract can repair damage from free radicals and increase the activity of the liver antioxidant defence mechanism (9). This plant is used to make "Bhringraj," a well-known ayurvedic medication for liver problems (9). In the rat model of hepatitis induced by D-galactosamine/lipopolysaccharide (D-GalN/LPS), the ethanolic extract of *Tridax procumbens* significantly elevated the levels of alanine transaminase, aspartate transaminase, lactate dehydrogenase, alkaline phosphatase and bilirubin, restoring them toward normal values. (7). Furthermore, *T. procumbens* ethanolic extract showed hepatoprotective effect against CCl_4, restoring the liver to its normal look and resembling the normal liver cells observed in rats (97).

Various dosages of *T. procumbens* ethanolic extract administered orally demonstrated the antioxidative and hepatoprotective effectiveness against liver damage caused by paracetamol (9). Additionally, male Wistar albino rats were protected against hepatotoxicity induced by D-galactosamine by methanol, chloroform and water extracts of *T. procumbens* flowers; the methanolic extract showed the highest efficacy because of its high phenolic contents. However, aqueous extract leaves have antioxidant properties, demonstrating hepatoprotective effects in rats (9, 28). Besides, the aerial parts of *T. procumbens* showed hepatoprotective effects and essential protection in alleviating D-galactosamine/lipopolysaccharide (98).

Anti-inflammatory activity

Numerous investigations have documented the anti-inflammatory properties of various *T. procumbens* extracts attributed to their active chemical components (78). Anti-inflammatory properties of *T. procumbens* extracts derived from numerous parts of the plant are well documented due to their active chemical ingredients. Anti-inflammatory activity, induced by carrageenan, correlated with diclofenac sodium in various experiments (78). *In vivo*, different authors have observed the anti-inflammatory effects of *T. procumbens* methanol extract (78, 99). *Tridax* leaves aqueous extract exhibited contractile action, in contrast to the control group. The aqueous tridax procumbens leaf extract (ATPLE)-treated group exhibited considerably greater contraction in response to Ca^{2+} activated K^+ channel (KCl), H1 receptor subtype activation and the M3 receptor acetylcholine, which relates to Gq and PKC (9). *In vivo* anti-inflammatory activity of methanol extract of *T. procumbens* leaves was shown in xylene-induced ear, carrageenan-induced paw, egg albumin and formalin-induced inflammation, in mice at 25–100µg/kg. The authors observed good anti-inflammatory effects in mice BALB/c (20–30g) (99). Various animal studies have shown that several extracts of *T. procumbens* have anti-inflammatory properties.

Anti-cancer activity

Cancer is one of the most prevalent diseases that can start in almost any organ or tissue of the body when abnormal cells grow uncontrollably. Treatments can include surgery, radiation therapy, chemotherapy, targeted therapy, immunotherapy and hormone therapy. However, naturally derived compounds from medicinal plants and their properties make them targets for potential anticancer treatments (100). In traditional medicine, *T. procumbens* has been used to treat various illnesses. However, there is no evidence regarding its historical use for cancer; nevertheless, recently, several new publications suggest that *T. procumbens* contains many potent anticancer compounds, including flavonoids, tannins and saponins (78). Using the 9(3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide assay (MTT assay), anticancer activity of 5,6-epoxy-3 hydroxy7-megastigmene-9-one was examined in leukemia (HL-60), gastric cells (SGC-7901) (58). The MTT test was used to determine the cytotoxicity of chemicals obtained from plants against human lung cancer cells (35).

In vitro MTT assay was used to assess the essential oil extracted from *T. procumbens* leaves for anticancer activity in the MCF-7 cell line. The results displayed that the essential oil had a strong anticancer effect, which could be explained by the occurrence of crucial terpenes like α-pinene and β-pinene (9). *Tridax procumbens* essential oil demonstrated excellent cytotoxicity, killing 70.28 % of cancer cells in 24 hr at a dose of 50 µg. This indicates that the oil effectively stops lung metastases of the B16F-10 cells in mice (78). Anticancer action by acetone and water extracts of *T. procumbens* flowers was examined. Contrary to the water extract (6.6 % cell death), the acetone extract displayed intense anticancer action against PC3 cell lines using the MTT test at a dose of 250 µg/mL (82.28 % cell death) (101).

The *T. procumbens* leaf acetone and aqueous extract demonstrated anticancer efficacy in PC3 cancer cells *in vitro* using the MTT and trypan blue exclusion assays. While the aqueous extract showed little anticancer effect, the acetone extract had intense anticancer action, resulting in 93 % cell death (78). *Tridax procumbens* leaves ethanol, acetone extracts (10–50 µg/mL) revealed anticancer action in lung cancer cells A-549, while water extract exhibited no anticancer activity (101). Further, the cytotoxicity impact of *T. procumbens* leaf methanol extract at 250 µg/mL was assessed in human lung cancer A-549 cells at 84 ± 2.8 % and human breast MCF-7 cells at 68 ± 3.1 % (86). Different cancer cell studies have demonstrated that the active chemicals in medicinal plants can prevent the proliferation of cancer cells.

Anti-diabetic activity

Diabetes mellitus is a chronic metabolic disorder characterised by hyperglycemia due to insufficient insulin production, impaired insulin action or both. It is a global health concern affecting millions of people and it's associated with serious complications. Synthetic drugs help lower blood sugar levels and improve insulin sensitivity but may also have side effects. Hence, herbal and natural anti-diabetics-based treatment is gaining interest in integrative medicine.

Ethanolic extract of *T. procumbens* showed antidiabetic action in Wistar rats induced by streptozotocin-nicotinamide (30). On the other hand, methanolic leaf and flower extract of *T. procumbens* revealed effective antidiabetic activity (85). Besides, *T. procumbens* leaf aqueous and alcoholic extracts dramatically lowered blood glucose levels in rats with alloxan-induced diabetes (98). Water, chloroform, alcoholic and petroleum ether extracts of *T. procumbens*

leaves were administered orally for seven days at 200 mg/kg. The results showed that these extracts significantly reduced blood glucose in rats with alloxan-induced diabetes, but petroleum extract showed very little antidiabetic activity (16).

The *T. procumbens* extract was extracted using 50 % methanol and tested for acute and sub chronic antihyperglycemic effects in alloxan-induced diabetic rats. Rats with diabetes revealed a decrease in fasting blood glucose when oral *T. procumbens* extract was administered at acute and sub chronic levels (250, 500 mg/kg b.wt.), but not in untreated rats (102). The antihyperglycemic effects were dose-independent, Oral Glucose Tolerance Test (OGTT) and body weight-maintained by antihyperglycemic action (102). Diabetics' chronic disease is inadequately controlled by insulin; hence, various plant extracts have shown a reduction in blood glucose levels.

Immunomodulatory activity

The immune system is critical in maintaining physiological homeostasis by defending the body against pathogens, removing damaged cells and controlling inflammation. Immunomodulatory activity refers to the ability of a substance to modify, regulate or normalise the immune response. This modulation can either enhance (immunostimulation) or suppress (immunosuppression) specific components of the immune system, depending on the therapeutic need (103).

Albino rats orogastrically dosed with *P. aeruginosa* and treated with ethanolic extracts of *T. procumbens* leaves have an immunomodulatory impact (98, 104). In animal models, plant leaf ethanol decoctions have been found to have immunomodulatory effects. Additionally, an increase in hemagglutination antibody and immunological response stimulation were observed (105). The humoral immune response was stimulated by the ethanol-insoluble fraction of *T. procumbens* extract, which also markedly enhanced leukocyte count, phagocytic index and splenic antibody-secreting cells (35). Further, *T. procumbens* ethanol-insoluble water extract revealed IP administration of TPEIF (0.25, 0.5 g/kg body weight) showed increased leucocyte count and splenic antibody-secreting cells (56). Similarly, ethanol-insoluble water extract has been shown to significantly raise phagocytic index and leukocyte count (84).

Anti-oxidant activity

2, 2-Diphenyl-1-Picrylhydrazyl (DPPH) and a vitamin as a positive control in the *in vitro* antioxidant assay of *Tridax* were assessed against three isolated flavonoids: 6-4′-trihydroxy-7-O-β-D-glucopyranoside, 3-O-methyl quercetin-4′-O-β-D-glucopyran-oside, Queracetangatin-3. The antioxidant capacity of compounds 3-O-methyl quercetin-4′-O-β-D-glucopyranoside and 6-O-trihydroxy-7-O-neohesperidoside was restricted, with IC_{20}> 100 µmol/L, whereas compound 6-O-trihydroxy-7-O-β-D-glucopyranoside exhibited little activity, with IC_{20}> 100 µmol/L (78, 80).

The *T. procumbens* has a high concentration of flavonoids, phenols, anthraquinones, vitamins A and C and carotenoids, which account for its intense antioxidant action (6, 106). Using the DPPH activity, *T. procumbens* essential oils have demonstrated antioxidant activity by lowering oxidative stress levels (6). *Tridax procumbens* leaves aqueous and ethanol extracts were examined using DPPH antioxidant assay. At a 200 µg/mL dose, the ethanol extract demonstrated better antioxidant activity (86). Another study assessed the antioxidant assay of two compounds of *T. procumbens*, 6,8,3′-trihydroxy-3,7,4′-trimethoxy flavone and 3′-dihydroxy-3,7,4′-trimethoxy-6-O-β-D-glucopyranosyl flavone. Comparing these two compounds to the standard control, their IC_{50} values were 0.03180 and 0.04618 mg/mL, respectively, indicating strong antioxidant activity, IC_{50} for Trolox = 0.00948 mg/mL (77).

Anti-parasitic activity

In vitro, the methanolic extract of *T. procumbens* exhibited 50 % inhibition at 3 µg/mL and reduced promastigote growth of *Leishmania mexicana,* which causes leishmaniasis illness (9, 81). Furthermore, *in vivo* experiments showed that *T. procumbens* has significant activity in *L. mexicana* and is a candidate for leishmanicidal activity. In *T. procumbens,* oxylipin, isocordoin, 20,40-dihydroxy-30-(g,g-dimethylallyl)-dihydrochalcone, cholestra-4,20,24-trien-3-one or pentalinosterol and 24-methylcholesta-4-24(28)-dien-3-one, cholest-4-en-3-one, 6,7-dihydroneridienone, neridienone and cholest-5,20,24-trien-3b-ol, metabolites showed an IC_{50} at 30 mg/mL against *L. mexicana* (107).

Water and ethanol decoctions of *T. procumbens* offer anti-plasmodial qualities that combat *Plasmodium falciparum*, which is resistant to chloroquine (105). *Tridax procumbens* demonstrated leishmanial action when crude extracts of the entire plant were used (60). Red blood cells were shielded from *P. falciparum* damaged by *T. procumbens* aqueous and ethanol extract, demonstrated by the tetrazolium-based colourimetric technique (108). The antiplasmodial properties of water, ethyl acetate, ethanol and chloroform extracts of *T. procumbens* flowers, leaves and stems were examined in Ghana (6). The water and ethanol infusions exhibit little toxicity to human red blood cells and possess anti-plasmodial qualities against the chloroquine-resistant parasite *P. falciparum (35).* In addition, *Tridax*, entire plant in methanol extracts were evaluated for leishmanicidal assay against promastigotes of *L. mexicana* in an *in vitro* assay (56). Thus, active phytochemicals can control parasitic growth and proliferation.

Insect repellent activity

Repellents act locally or at a distance, deterring an arthropod from flying to, landing on or biting human or animal skin (109). Insect repellents act primarily by interfering with the insect's olfactory or sensory receptors, thereby modifying their behaviour and keeping them away from the treated surface, human, animal or plant (110). The *T. procumbens* leaves produce some essential oils, which act as a source of insect repellent (35). *Tridax procumbens* contains a significant chemical constituent, α-terpinene, α-terpineol and β-pinene, which provides a repellency against *A. stephensi* (12). The plant essential oils do not cause skin irritation, hot sensations or rashes on the arms and can be used directly (9). In mosquito cages, essential oils extracted from leaves by condensation, their ability to locally resist the malaria parasite *A. stephensi* was examined (105). *Tridax procumbens* leaf extracts in hexane, chloroform, ethyl acetate and acetone have adulticidal activity against *A. stephensi* (111). On the contrary, chloroform and acetone extracts of *T. procumbens* have the maximum adulticidal activity (78, 112).

Hemostatic activity

In vitro, the hemostatic properties of the plant leaves in various solvent extracts were determined by employing Lee-White's method (105). When the hemostatic activity of several extracts from *T. procumbens* leaves was examined, the ethanol extract consistently shortened the clotting time in the blood samples (16).

Further, *T. procumbens* leaves water extract showed significant blood coagulation activity; for those reasons, it may be used as a potent hemostatic agent (9). Plant-based flavonoids, which stimulate osteoblasts and inhibit osteoclasts, can control bone homeostasis. *Tridax procumbens* fraction (TPF) can potentially treat disorders such as osteoporosis associated with bone loss by blocking receptor activator of nuclear factor-κB ligand (RANKL)-induced osteoclast growth and pit formation in primary osteoclastic cells. In mice, TPF boosted bone formation indices and inhibited the growth of osteoclasts (35).

Wound healing activity

Studies have shown that *T. procumbens* ethanolic leaf extracts can heal wounds in diabetic and non-diabetic animals. Animals treated with 5 % and 2.5 % (w/w) extract showed a noticeable difference in wound index, epithelization period and wound contraction (113). In experimental male Wistar rats, water extract of *T. procumbens* leaves accelerated healing and overcame steroid-depressed healing (56). *Tridax procumbens* has been used traditionally to promote wound healing and has strong anti-inflammatory, anti-microbial and anticancer effects (114). Mice treated with *T. procumbens* leaf juice at a 1 mg/g concentration exhibited increased vascularity, fibroblast number, collagen content, re-epithelization and wound contraction parameters. Additionally, it was noted that high dosages cause inflammation, oedematous tissue and vascularity and it was determined that this plant extract's pro-healing properties depend on dosage (115). In a different study, mice with excision wounds showed improved results after 15 days using an ointment formulation containing hydroalcoholic leaf extract of *T. procumbens* instead of the blank ointment model.

Conclusion

In conclusion, this review highlights *in vitro* and *in vivo* the significant therapeutic potential of *T. procumbens* which is traditionally used for treating ailments such as anti-diabetic, anti-ulcer, anti-cancer etc. *Tridax procumbens* is one of India's most widely recognized herbal remedies. It contains diverse bioactive compounds, including alkaloids, phenols, flavonoids and terpenoids, that have shown promising pharmacological activities such as antioxidant, anti-inflammatory, antimicrobial and more. Despite its traditional uses and known benefits, further research must identify and characterize the specific bioactive compounds responsible for these effects and mechanism. Advanced extraction methods and compound profiling are essential to better understanding the plant's therapeutic mechanisms. This review highlights the historical significance and the need for continued investigation into *T. procumbens*, as it holds promise for uncovering additional pharmacological properties yet to be fully explored to bridge the gap. Future studies targeting the isolation and functional analysis of its active constituents may contribute significantly to developing novel, plant-based pharmaceuticals and pave the way to creating more advanced conventional medications.

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Authors' contributions

HK carried out the literature collection and drafted the manuscript. AB, KB, KM and GB participated and carried out the table and figure preparation, NB conceived the idea and critical review of the manuscript. JKS and GS participated and improved the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

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