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REVIEW ARTICLE

Pharmacological and nutraceutical potential of *Rhododendron arboreum* and *Trichosanthes dioica*: A review

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Abstract

Rhododendron arboreum (*R. arboreum*) and *Trichosanthes dioica* (*T. dioica*) are two ethnobotanically notable plants that are well-known for their diverse pharmacological characteristics as well as their abundant phytochemical composition. Traditionally utilized in Himalayan regions, *R. arboreum* is abundant in flavonoids, phenolics, saponins, alkaloids and vital minerals. Its flowers are especially valued in local foods and drink preparations. Likewise, *T. dioica*, a popular vegetable in South Asia, has a variety of bioactive components that support its use in traditional medicine and nutrition such as triterpenes, sterols, glycosides, vitamins and essential fatty acids. The medicinal properties of both plants including their antibacterial, hepatoprotective, antidiabetic, anti-inflammatory and antioxidant properties are encouraging for therapeutic uses. They are excellent candidates for the creation of functional foods and nutraceuticals due to their high nutritional content and health-promoting phytochemicals. While their traditional dietary use is well established, further toxicological and pharmacological evaluations remain necessary. To guarantee safety and effectiveness, this is particularly important when taken in extract form or at dosages greater than those found in food. The review emphasizes the importance of their varied phytochemical compositions and pharmacological properties, demonstrating their significance as useful plant resources for both nutrition and medicine. This review integrates traditional ethnobotanical knowledge with contemporary pharmacological evidence, providing a consolidated resource to support future nutraceutical and therapeutic research on these species.

Keywords: medicinal plants; nutraceuticals; pharmacological activities; phytochemicals; *Rhododendron arboretum*; *Trichosanthes dioica*

Introduction

Medicinal plants have been integral to healthcare since ancient times with traditional knowledge adapting to environmental, cultural and technological changes (1). They remain vital in developing plant-based natural products due to their strong pharmacological effects, affordability and generally minimal toxicity (2).

According to the World Health Organization, 70-80 % of the global population relies on herbs for primary healthcare with over 53,000 species historically used to treat human illnesses (3). Interest in plant-derived bioactive compounds has grown alongside the rise in chronic diseases such as diabetes, cancer and cardiovascular disorders (4). Because of their numerous bioactive potentials and functional qualities with minimal adverse effects, plant-derived bioactive peptides have garnered a lot of attention lately for use in nutraceuticals and functional products (5).

Research trends and renewed scientific interest in the drug discovery and development of plant-derived natural products made it abundantly evident that this field is one of the possible future sources of novel therapeutic agents. Plant metabolites are being optimized in this type of research to create possible analogues that can exhibit the required safety and effectiveness (6). Nutraceuticals such as dietary supplements, functional foods and herbal products bridge the gap between pharmaceuticals and nutrition offering disease prevention and health promotion (7, 8). The increased demand from consumers for natural and alternative healthcare solutions is driving the rapid growth of the worldwide herbal medicine market. The market for scientifically proven nutraceutical supplements is growing as customers look for natural and holistic health solutions (9). Their phytochemical diversity including flavonoids, polyphenols, alkaloids, terpenoids and essential oils underscores the importance of studying phytochemistry and pharmacology to maximize health benefits (10).

Rhododendron arboreum and *Trichosanthes dioica* are medicinal plants that have garnered attention because of their numerous traditional applications and new scientific data proving their pharmacological potentials. An evergreen shrub indigenous to the Himalayas, *R. arboreum* is well-known for its medicinal qualities and its vivid red blossoms (11, 12). The plant has wide medicinal potentialities due to its bioactive components which include flavonoids, tannins, saponins and phenolic acids. Numerous studies show that *R. arboreum* has antimicrobial, anti-inflammatory, antioxidant, hepatoprotective, anti-diabetic and anti-diarrheal activities (11).

On the other hand, the edible plant *T. dioica* has hypolipidemic, cardiotonic, diuretic, ulcer-preventive, antidiabetic, anti-inflammatory and anti-cancer activities. Also, the plant exhibits strong antioxidant properties. The plant contains a variety of chemical components including tetra and pentacyclic triterpenes, alkaloids, peptides, tannins, vitamin A, vitamin C and saponins (12).

Therefore, this review aims to compile and critically evaluate the ethnobotanical, phytochemical and pharmacological data on *R. arboreum* and *T. dioica* highlighting their potential applications in nutraceuticals and medicine and identifying research gaps to guide future investigations.

Rhododendron arboreum

R. arboreum is an evergreen shrub or small tree that grows widely and has pink and red blooms. The words 'rhodo' which means rose and 'dendron' which means tree comes from the Greek together forming the name '*Rhododendron*' (13). The commonly used vernacular names (Table 1) and taxonomical classification (Table 2) of this plant are described below to comprehend its scientific identification and regional relevance (14).

Table 1. Vernacular names of *R. arboreum*

Language/Region	Vernacular Name
Hindi/Garhwali	Burans or Lalburans
Nepali	Laligurans
Punjabi	Adrawal
Kashmiri	Kamri, Cham
Khasi (Meghalaya)	Dieng-tiw-saw
Bengali	Baras
Kumaoni	Eras
Tamil Nadu	Billi or Allingi
Malayalam (Kerala)	Kattupoovarasu

Table 2. Taxonomical classification of *R. arboreum*

Kingdom	Plantae
Phylum	Magnoliophyta
Class	Angiospermae
Order	Ericales
Family	Ericaceae
Genus	Rhododendron
Sub-genus	Hymenanthes
Species	*Rhododendron arboreum*

Botanical description

A prominent and highly regarded species of the *Rhododendron* genus, *R. arboreum,* gets its name from the Latin '*arboreum*,' which means 'tree-like'. *R. arboreum*, the state flower of Nagaland, state tree of Uttarakhand and Sikkim and national flower of Nepal, holds sociocultural significance. Along with areas of North America, Europe and Asia, such as China, New Guinea, Malaysia, Indonesia, Thailand, Myanmar and the Philippines, the species is extensively dispersed throughout the Himalayan region (15).

The vibrant flowers and distinctive leaves of this Himalayan species are valued for their therapeutic and nutraceutical potential (Fig. 1). This tree which may reach a height of 15 m belongs to the Ericaceae family and grows between 1500 and 3000 m above sea level in the Himalayan region. The reddish-brown bark is moderately tough and exfoliates in thin flakes. The trunk often gnarled or branched (15, 16).

The leaves are lanceolate to oblong with a length of 10 to 20 cm and a width of around 3.6 cm. Immature leaves are primarily clustered toward the tips of branches and their petioles are covered in white scales. Mature leaves have a cinnamon or reddish -brown underside with thin felted hairs and a bright green upper surface with highly impressed mid-veins and lateral veins (16).

The massive, globose cymes of blooms are prominent and can bear up to 20 blossoms per truss. Bloom color varies from scarlet to white with red forms more common at lower elevations (17). The corolla is bell-shaped and tubular, measuring about 4 to 5 cm in length. It has broad lobes and a defined funnel-shaped tube. There are delicate clefts in the calyx. Ten to twelve stamens with filiform white filaments are produced by each flower; the anthers are elliptical and the stamens are hypogynous and decreasing in length. The style is capitate (18).

The fruit is an oblong, curved capsule made of fine lobes that can grow up to 3.8 cm in length and 1.25 cm in breadth. When the capsule reaches maturity, it releases many tiny, compressed, linear, thin seeds each of which is encased in an obvolute membrane wing to facilitate wind distribution (19).

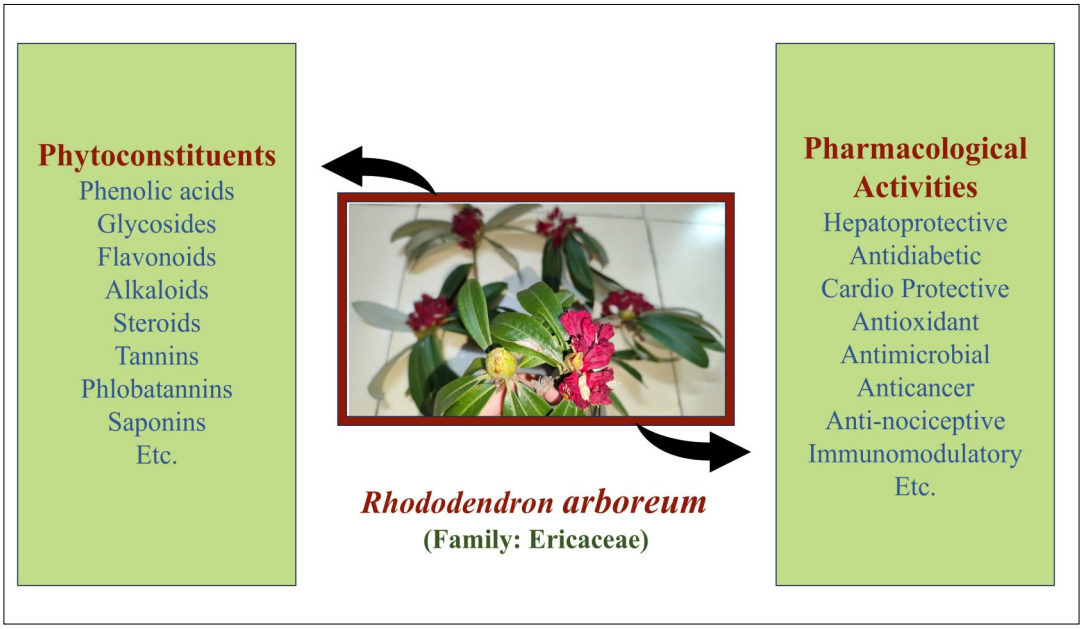


Fig. 1. Phytochemical constituents and corresponding pharmacological activities of *Rhododendron arboreum* (family: Ericaceae).

Traditional and ethnomedicinal uses

Many human illnesses including blood dysentery, headaches, asthma, coughs, stomach aches, fevers, inflammations and fungal infections have long been treated using *Rhododendron* plants. These have pharmacological, therapeutic and economic significance. It is also believed to be a good source of secondary metabolites (20). They are eaten raw, cooked into juices or added to regional drinks that are thought to have cooling and healing qualities. Flower juice had been in use as a refresher and to treat high blood pressure, diabetes, cough, headache and stomachache (21). The Raji tribal population in Uttarakhand is familiar with buransh juice, an ethnomedicine made from the red blooms of *R. arboreum*. In addition to being a popular daily beverage and appetizer, it helps prevent the 'high-altitude sicknesses. Traditionally used to cure diarrhea, dysentery, asthma, fever, stomach discomfort, headache, nosebleed, rheumatism, wounds and high blood pressure, the juice is frequently made as a squash or cold beverage (22). There are two ways to extract the juice from this plant: hot pressing and cold pressing. However, the traditional hot-pressing procedure is done in a processor (23). This plant's leaves have long been used as a poultice and astringent, crushed into a paste and used to cure headache by applying it to the forehead (24). Also used for honey, pickles, juices, jams and syrups (25). Additionally, these plants can be used to make agricultural tools, fuel wood and domestic products (21).

Phytochemical constituents

Numerous studies have been conducted on *R. arboreum* because of its extensive phytochemical profile which supports its pharmacological and therapeutic benefits. Phenolic acids, glycosides, flavonoids, alkaloids, steroids, tannins, phlobatannins and saponins are among the bioactive substances found in the plant's flowers, leaves and bark. Manganese, iron, zinc, copper, chromium and other vital minerals are also present. These micronutrients and phytochemicals, particularly the secondary metabolites are essential for plant defense and have been associated with various health benefits as documented in existing studies (26).

Several bioactive chemicals have been found in this plant, according to phytochemical studies. 34 phytochemical components were found in the methanolic leaf extract after GC-MS analysis including triterpenes (alpha-amyrin, beta-amyrin) and unsaturated fatty acids (linoleic acid, α-linolenic acid) which are widely recognized for their anti-inflammatory and cardioprotective roles, beta-citronellol, methyl ester, linoleyl alcohol, heptadecane, dodecane, tetradecane, 2,6-dihexadecanoate, 22-stigmasten-3-one, 9,12-octadecadienoic acid, dibutyl phthalate and L-ascorbic acid were among the main substances found in the extract. These major phytoconstituents have been associated with diverse pharmacological activities including antimicrobial, anticancer, antiarthritic, anti-inflammatory and antiviral effects (27).

13 different phytochemicals were also found after the ethanolic leaf extract was analyzed. The main ingredients of these were identified as 1-hexadecene, 1,2,3-propanetriyl ester, 1 -octadecanol, geraniol formate and docosanoic acid which further supports the plant's pharmacological relevance (28).

Flavonoids, alkaloids, saponins and phenolic compounds were confirmed to be present in the ethanolic flower extract of *R. arboreum* using phytochemical screening and GC-MS analysis. While 0.11 ± 0.009 mg/g of saponins and 0.03 ± 0.002 mg/g of alkaloids were obtained in smaller proportions, 33.25 ± 0.89 mg RE/g of flavonoids and 65.50 ± 1.12 mg GAE/g of total phenols were obtained in high concentrations. There were many volatile chemicals identified by GC-MS analysis; however, the most prevalent one was n-hexadecanoic acid (11.81%) which was followed by linolenyl alcohol (8.61 %), β- and γ-sitosterol (7.33 %), stigmasterol (7.33 %), stearic acid (3.18 %) and α-linolenic acid (1.33 %). Vitamin E, essential fatty acids and other bioactive substances were significantly present in the extract. The elevated levels of phenolic compounds suggest that the flowers possess considerable antioxidant and antimicrobial properties (29).

The phytoconstituents isolated from *R. arboreum* and their corresponding chemical structures are detailed in Table 3.

Pharmacological activities

Hepatoprotective: *R. arboreum* dramatically reversed the liver damage caused by paracetamol, exhibiting moderate to good hepatoprotective properties. The extract showed promise in liver protection by restoring important biochemical markers such as direct bilirubin, total bilirubin, SGPT and SGOT levels. Additionally, it was observed that efficacy was dose-dependent (30).

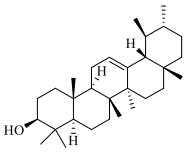
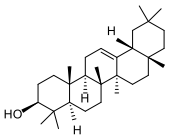
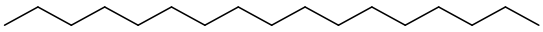
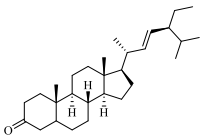
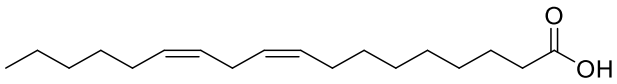
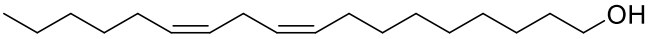
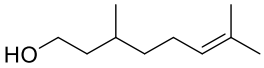
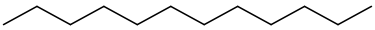
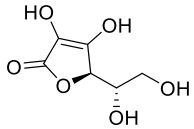
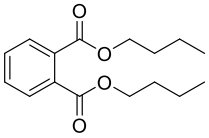
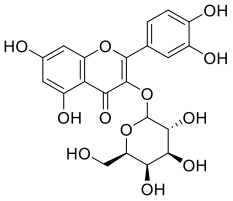
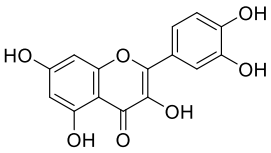
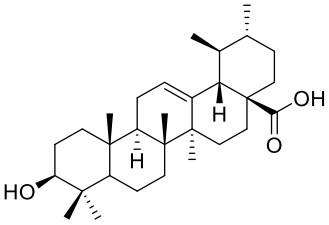
Antidiabetic: In albino rats, both healthy and diabetic caused by streptozotocin, the ethanolic extract of *R. arboreum* has shown notable hypoglycemic effects. In normal, glucose-overloaded and diabetic rats, the extract lowered blood glucose levels indicating processes that include improved β-cell regeneration, higher glucose absorption, improved insulin production and altered lipid and carbohydrate metabolism. Pancreatic cell repair and inflammation reduction may be further supported by the antioxidant properties of the extract which increase both enzymatic and non-enzymatic antioxidant levels. According to phytochemical investigation, the antidiabetic potential of the plant was aided by the presence of tannins and flavonoids which are substances with insulin-secretagogues and insulin-mimetic properties (31).

Cardio-protective: Significant cardio-protective benefits against doxorubicin-induced cardiotoxicity have been demonstrated by *R. arboreum* leaf extract. The extract normalized ECG abnormalities such as QT prolongation and QRS complex widening and decreased the elevated cardiac biomarkers including LDH, CK-NAC, CK-MB, AST and ALT in experimental rodents. According to these results, the extract may have a cardioprotective impact by modifying pro-inflammatory mediators and having antioxidant effects which would help to restore heart function and prevent cellular damage (32).

Antioxidant: Lipid peroxidation inhibitory and nitric oxide scavenging tests revealed dose-dependent antioxidant activity in the methanolic extracts of *R. arboreum* leaves. Its ability to scavenge radicals is probably because of the existence of various phytochemicals as polyphenols, gallic acid, rutin and ellagic acid. The extract demonstrated its promise as a natural antioxidant agent in therapeutic applications by successfully reducing the formation of free radicals (33).

Antimicrobial: Significant antimicrobial effect was shown by *R. arboreum* extracts against several bacterial pathogens such as *B. cereus*, *Pseudomonas, S. typhi*, *E. coli* and *S. aureus*. The methanolic extract demonstrated the largest spectrum among the

Table 3. Phytochemicals isolated from *R. arboreum*

S. No.	IUPAC Name	Molecular Formula	Structure
1	Alpha-amyrin	$C_{30}H_{50}O$	
2	Beta-amyrin	$C_{30}H_{50}O$	
3	Heptadecane	$C_{21}H_{44}$	
4	22-stigmasten-3-one	$C_{29}H_{48}O$	
5	tetradecane	$C_{14}H_{30}$	
6	linoleic acid	$C_{18}H_{32}O_2$	
7	linoleyl alcohol	$C_{18}H_{34}O$	
8	beta-citronellol	$C_{10}H_{20}O$	
9	dodecane	$C_{12}H_{26}$	
10	L-ascorbic acid	$C_6H_8O_6$	
11	dibutyl phthalate	$C_{16}H_{22}O_4$	
12	Quercetin-3-O-galactoside	$C_{21}H_{20}O_{12}$	
13	Quercetin	$C_{15}H_{10}O_7$	
14	Ursolic acid	$C_{30}H_{48}O$	

several solvent extracts examined, demonstrating efficacy against all tested bacteria except *Shigella flexneri*. While the acetone extract showed modest effectiveness towards *E. coli*, *S. aureus* and *S. typhi*, the ethanol extract was notably potent against *S. aureus*. There was no effect from the petroleum ether extract. Low doses of methanolic and acetone extracts were found to be adequate to inhibit bacterial growth, especially against *S. aureus*, according to minimum inhibitory concentration tests. This supported the potential of the extracts for use in treating microbial infections and validated the plant's traditional medicinal uses (34).

Anticancer: 15-oxoursolic acid, a triterpenoid that exhibits considerable cytotoxicity against numerous cancer cell lines including Hep G2, MDR 2780AD and H157 was identified by phytochemical investigation of *R. arboreum* bark. Key functional groups (C-3 hydroxyl and C-17 carbonyl) are thought to be responsible for its efficacy, indicating that apoptosis induction is a possible mechanism. Its promise as a lead chemical in cancer therapy is supported by these findings (35). Significant dose-dependent cytotoxicity was shown by methanolic extracts of *R. arboreum* leaves and flowers against the cancer cell lines HeLa, MCF-7 and A549. Flower extract was most efficient against MCF-7 cells (up to 84.93 % at 500 mg/mL) whilst leaf extract had the highest inhibition in A549 cells (up to 75.08 % at 500 mg/mL). High concentrations of ellagic acid, a polyphenol with known antiproliferative qualities, were found by UHPLC analysis which probably contributed to the cytotoxicity observed. Additional bioactive substances with documented anticancer potential were discovered by GC-MS, such as gallic acid, linoleic acid and palmitic acid (33).

Anti-nociceptive: Ethyl acetate, chloroform, n-hexane, n-butanol, aqueous and methanolic bark extract of *R. arboreum* were tested for antinociceptive properties. In the acetic acid-induced writhing test, 200 mg/kg of the ethyl acetate fraction was given intraperitoneally, demonstrating the strongest analgesic efficacy (82 %) among them. Significant analgesic effects were also shown by the chloroform and the crude extract fraction which showed 65.09 % and 67.89 % inhibition, respectively (36).

Immunomodulatory: Increased phagocytosis of dead *Candida albicans* and improved neutrophil function in the nitroblue tetrazolium test are two indications of the strong immunomodulatory action of *R. arboreum* leaf extracts. Several extracts significantly enhance the phagocytic index and leukocyte activity. These findings imply that the bioactive substances in the plant can successfully regulate innate immune responses (37).

Nutraceutical potential and functional food applications

Nearly every part of the *R. arboreum* which is used extensively in traditional medicine, is appreciated for its aromatic, therapeutic and nutritional properties. Its flowers are particularly well-known for their stimulating and medicinal effects. Traditionally, petals are incorporated into various foods like Indian breads (roti, parathas), ground into chutneys, squashes, syrups and local wine (sur') to help prevent high-altitude sickness. According to studies, the flower juice is high in flavonoids, anthocyanins, ascorbic acid and carotenoids. It has great promise in the beverage sector and can vary in taste, pH and acidity depending on fortification. This juice is perfect for functional beverages since adding ginseng or aloe vera improves its nutritional profile (38).

Trichosanthes dioica

Fruit-like cucurbit vegetables are produced by the dioecious climbing plant *T. dioica*. The male and female sexes of this perennial climber are found on separate plants. Green-stage immature fruits are frequently eaten as vegetables after being cooked (39, 40). To understand the cultural relevance and botanical identity of *T. dioica*, its vernacular names (Table 4) and taxonomical classification (Table 5) are presented below (40).

Botanical description

Among the most well-known species of the *Trichosanthes* genus in tropical Asian nations, especially Bangladesh and India, is *T. dioica* which is consumed as a vegetable from February to September. Believed to have evolved in the Indo-Malayan or Indian subcontinent. India, Pakistan, Bangladesh, Nepal, Myanmar and Sri Lanka are the primary growing countries for it (41). In the Indian states of Assam, West Bengal, Uttar Pradesh and Bihar, it is a significant crop that is widely planted in riverbeds (42).

Edible fruit, commonly used as a vegetable in traditional diets and known for its nutritional and ethnomedicinal value (Fig. 2). It is a dioecious herbaceous perennial vine that belongs to the Cucurbitaceae family. Its climbing nature is supported by conspicuous, thick tendrils on slender, pencil-thick stems. Propagated mainly by stem cuttings and tuberous taproots due to poor seed germination (43).

Dark green, stiff and cordate to rectangular, the leaves have sinuate-dentate margins and an acute apex. They might have oval or elongated shapes and are not lobed (44, 45).

The calyx tube of each bracteate flower is oblong-cylindrical. From initiation to anthesis, pistillate flowers take roughly 16-19 days, whilst staminate flowers take roughly 10-14 days. For about 14 hours, the stigma is still active (44, 45).

The fruit is dark green with white or pale green streaks, smooth and oblong to globose. Fruits are picked 15-18 days after pollination and are usually 10-12 cm long and 30-50 g in weight. Fruits are still green three to four weeks after pollination, but they contain more than 20 hard-coated seeds. Fruits are divided into four groups according to their size, form and striation: tapering (5-8 cm), green and striped, roundish (5-8 cm) with white stripes, broad (10-16 cm) with very light stripes and long (10-13 cm) with white stripes (45, 46).

Table 4. Vernacular names of *T. dioica*

Language/Region	Vernacular Name
Hindi	Parwal
Bengali	Potol
Telugu	Chedupotla
Malayalam (Kerala)	Patolam
Marathi	Paraval
Gujarati	Paraval
Tamil	Pudalai
Kannada (Karnataka)	Kaddupadaval
Sanskrit	Putulika
English	Pointed Gourd

Table 5. Taxonomical classification of *T. dioica*

Kingdom	Plantae
Division	Tracheophyta
Class	Magnoliopsida
Order	Cucurbitales
Family	Cucurbitaceae
Genus	Trichosanthes
Species	Dioica

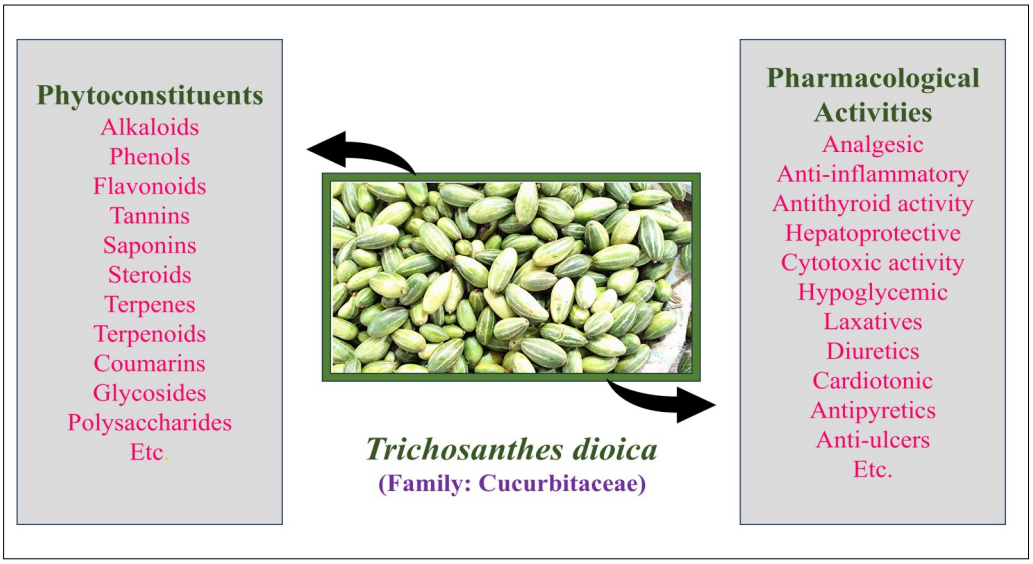


Fig. 2. Phytochemical constituents and corresponding pharmacological activities of *Trichosanthes dioica* (Family: Cucurbitaceae).

Traditional and ethnomedicinal uses

T. dioica is recognized for its ethnomedicinal attributes as well as its nutritional worth. In addition to being used industrially to manufacture pickles, jams and jellies, the unripe fruit is frequently cooked either by itself or in combination with other meals. Its nutritional value has increased its global demand. Ayurvedic treatments and folk medicine have long employed a variety of plant parts to treat several different types of diseases (41).

This has long been utilized as a dietary aid for recovery from disease or trauma and is acknowledged for its medicinal uses in many ancient systems, including Siddha, Ayurveda and Unani. According to Charaka Samhita, the ancient Ayurvedic text, the plant's fruits and leaves can be used in the treatment of alcoholism and jaundice (40).

The species is used extensively in Ayurvedic and Siddha medicine to cure a range of illnesses such as bilious fever, bronchitis, constipation and cancer-like disorders; it is also prescribed as a diuretic, appetite stimulant and digestive aid; the fruit is especially well-known for its ability to manage spermatorrhea; it is also used as a cooling agent, laxative and in postpartum care for women; it also has antiulcer properties (47). Ayurveda states that its root is a potent purgative as well as a tonic and febrifuge which can be used in the treatment of ascites, jaundice and anasarca (48).

Phytochemical constituents

According to phytochemical screening, secondary metabolites, including alkaloids, phenols, flavonoids, tannins, saponins, steroids, terpenes, terpenoids, coumarins, glycosides and polysaccharides are present in the fruit of *T. dioica* (49, 50).

GC-MS analysis showed the presence of 11 components in the aqueous extract of *T. dioica* root. Eicosane 2-methyl, octadecane, methoxyacetic acid, 2-methylhexacosane, heptacosane and octacosane were the most common phytoconstituents (51).

Phytochemical screening revealed the eistance of flavonoids, tannins, saponins, phenols, vitamin A and vitamin C in *T. dioica.* Cucurbita 5,24-dienol, hentriacontane-a phytosterol, an amorphous saponin, a non-nitrogenous bitter glucosidic principle, tannin, essential oil, fixed oil and fatty acids (for example, saturated, oleic, linoleic and elaeostearic acids) are among the chemical constituents that have been isolated from this plant (52).

There are a wide variety of phytochemicals in *T. dioica*. These include triterpenes which are mostly found in roots and seeds, represented by β-amyrin, α-amyrin, lupeol, euphol, tirucallol, taraxerol and cycloartanol. Numerous sterols, including 24-methylcholesterol, 24-methylenecholesterol, stigmasterol, avenasterol and β-sitosterol, are also produced by the plant. Proteins like trichosanthin, lectins andglycosides like colocynthin and saponins are reported from ths plant. Essential fatty acids such as linoleic, oleic and elaeostearic acid along with vitamins A, C, thiamine, riboflavin and nicotinic acid are abundant in seeds and fruits. The plant also includes a variety of additional components including 5-hydroxytryptamine, hentriacontane, carotene, fixed oils, essential oils, tannins and peptides in addition to minerals like calcium, iron and magnesium. This diverse phytochemical profile underlies a broad spectrum of reported pharmacological activities including antihyperglycemic, antihyperlipidemic, antitumor, cytotoxic, arsenic-poisoning-ameliorative, anti-inflammatory, antidiarrhoeal effects etc. The pharmacological relevance of the bioactive substances from *T. dioica* and its possible uses in nutrition and health are widely reported (41).

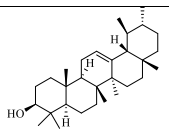
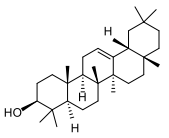
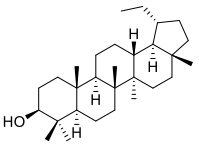
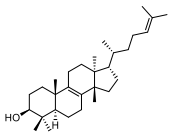
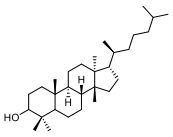
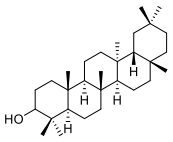
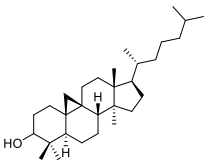
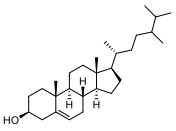
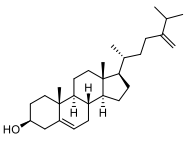
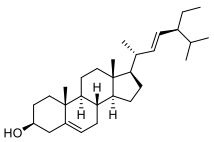
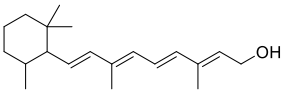
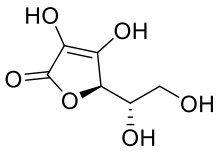
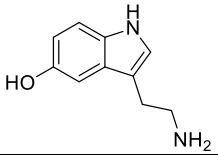
The phytoconstituents isolated from *T. dioica* and their corresponding chemical structures are summarised in Table 6.

Pharmacological activities

Analgesic: Formalin-induced paw-licking and acetic acid-induced writhing models show that *T. dioica* leaves have strong analgesic effects. Writhing was inhibited by the alcoholic extract by 48.39 %, suggesting that prostaglandin production suppression is the likely mechanism of peripheral analgesic effects. The extract decreased pain behaviour in the early (neurogenic) and late (inflammatory) phases of the formalin test, revealing a mix of peripheral and central analgesic mechanisms (53).

Anti-inflammatory: The carrageenan-induced paw edema model proved that *T. dioica* leaves have strong anti-inflammatory properties. At 200 mg/kg, both ethanolic and aqueous extracts dramatically decreased inflammation as compared to the control; however, the ethanolic extract (44.44 %) was more effective than the aqueous extract (38.88 %). The results show a moderate but substantial ($p<0.01$) edema-suppressant impact, indicating the potential of *T. dioica* as a natural anti-inflammatory agent, despite its lack of potency compared to the conventional medication diclofenac (54).

Table 6. Phytochemicals isolated from *T. dioica*

S. No.	IUPAC Name	Molecular Formula	Structure
1	Alpha-amyrin	$C_{30}H_{50}O$	
2	Beta-amyrin	$C_{30}H_{50}O$	
3	lupeol	$C_{30}H_{50}O$	
4	euphol	$C_{30}H_{50}O$	
5	tirucallol	$C_{30}H_{50}O$	
6	taraxerol	$C_{30}H_{50}O$	
7	cycloartanol.	$C_{30}H_{50}O$	
8	24-methylcholesterol	$C_{28}H_{48}O$	
9	24-methylenecholesterol	$C_{28}H_{46}O$	
10	stigmasterol	$C_{29}H_{48}O$	
11	Vitamin A	$C_{20}H_{30}O$	
12	L-ascorbic acid	$C_6H_8O_6$	
13	5-hydroxytryptamine	$C_{10}H_{12}N_2O$	

Anti-thyroid activity: In thyrotoxicosis caused by L-thyroxin (L-T_4), the peel extract of *T. dioica* has strong anti-thyroid action. Thyroid hormone (T_4 and T_3) levels in thyrotoxic mice were markedly reduced by administering the peel extract at doses of 25 and 50 mg/kg. The extract also improved antioxidant levels and decreased hepatic 5′-monodeiodinase I (5′D1) activity and lipid peroxidation, indicating that it may help to treat thyroid hormone imbalance and oxidative damage linked to thyrotoxicosis (55).

Hepatoprotective: In rats with hepatotoxic reactions generated by D-galactosamine, the ethanolic extract of *T. dioica* leaves demonstrated notable hepatoprotective efficacy. Significantly lowering increased serum levels of bilirubin, ALT, AST and ALP after pretreatment with the extract (250 and 500 mg/kg) suggested protection against liver damage. These observed effects were like those of silymarin (standard drug). The potential of the extract to mitigate hepatic injury was further supported by histopathological examinations which further verified the repair of liver architecture (56).

Cytotoxic activity: The human colorectal carcinoma cell lines (HT29 and HCT116) were significantly affected cytotoxically by the methanolic and fractionated extracts of *T. dioica* leaves. With an IC_{50} of 15.12 µg/mL on HCT 116 cells, the ethyl acetate fraction exhibited the highest cytotoxicity of all the studied extracts. Apoptosis-related morphological alterations and nuclear fragmentation were verified using confocal microscopy. Additionally, the extract caused sub-G0/G1 phase cell cycle arrest which may indicate apoptotic cell death. These findings show that *T. dioica* has the potential to be a natural source of anticancer compounds (57).

Hypoglycemic: Rats with diabetes induced by streptozotocin showed notable hypoglycemic action in response to ethanolic extracts of *T. dioica* (fruit and leaf). Oral glucose tolerance tests and a 28-day chronic study demonstrated a substantial drop in blood glucose levels following treatment with these extracts. Through improved glucose consumption and possibly improved insulin sensitivity or pancreatic β-cell activity, the extracts successfully reduced hyperglycemia. The traditional usage of *T. dioica* in the treatment of diabetes mellitus was supported by the glucose-lowering effect which was comparable to that of the standard drug glibenclamide (58).

Nutraceutical potential and functional food applications

Essential nutrients, including vitamins, minerals (such as Fe, Ca and Mg) and non-nutritive phytochemicals are abundant in ethnic vegetables and can help alleviate micronutrient deficiencies. Often referred to as the 'King of gourds,'" pointed gourds are valued for their great nutritional value and potential medical uses. Its leaf juice has long been used as a febrifuge and tonic for ailments like liver enlargement, edema and alopecia. Additionally, the leaves are used in Ayurvedic medicine as laxatives, diuretics, cardiotonics, antipyretics and anti-ulcers. Triterpenes, proteins, peptides, alkaloids, tannins, saponins and vitamins A and C are all present in *T. dioica*. As a vegetable, *T. dioica* is essential to the food traditions of many peoples and various regions. Their phytochemical components including micronutrients are crucial for human health. Consuming this vegetable is advised as a beneficial way to enhance nutrition and for the potential to delay the onset of chronic illnesses (59).

Future perspectives

R. arboreum and *T. dioica* have extensive phytochemical and nutritional profiles that make them excellent sources of nutraceuticals and functional foods. Future studies should focus on investigating innovative ways to use these plants in items such as health supplements, drinks and fortified foods. Their usefulness and consumer appeal can be further increased by developments in extraction technology, bioavailability enhancementand preservation techniques. There is also significant scope for exploring their synergistic effects with other medicinal or dietary plants to develop multifunctional health products. Modern pharmacological techniques combined with ethnobotanical knowledge may open up novel opportunities for preventative healthcare applications especially in the areas of metabolic, inflammatory and degenerative diseases.

A comparative summary of major phytochemical classes and their primary bioactivities in *R. arboreum* and *T. dioica* is presented in Table 7, highlighting shared bioactive compound classes underlying many therapeutic properties.

Future research should focus on standardizing extraction protocols, identifying clinically relevant bioactives, elucidating molecular mechanisms of action and conducting well-designed clinical trials to confirm safety and efficacy. Development of optimized delivery systems and formulation strategies will further enhance therapeutic potential and functional food applications.

Summary of future applications

- Standardized extracts for reliable therapeutic effects.
- Novel food and supplement formulations with enhanced bioavailability.
- Clinical validation of pharmacological benefits.
- Functional food and nutraceutical product development.
- Synergistic blends with other medicinal plants.

Table 7. Comparative overview of major phytochemical classes in *R. arboreum* and *T. dioica* with their corresponding primary pharmacological activities

Phytochemical Class	*Rhododendron arboreum*	*Trichosanthes dioica*	Primary Bioactivities
Flavonoids	Present in flowers, leaves, bark	Present in fruits and leaves	Antioxidant, anti-inflammatory
Triterpenoids	Present	Present	Anti-inflammatory, hepatoprotective
Saponins	Present	Present	Antimicrobial, antidiabetic
Phenolic acids	Present	Present	Antioxidant, cytoprotective
Alkaloids	Present	Present	Antimicrobial, anti-inflammatory
Steroids	Present	Present	Hepatoprotective
Minerals	Mn, Fe, Zn, Cu, Cr present	Trace elements present	Nutritional support, metabolic regulation

Conclusion

In addition to their importance in traditional medicine, *R. arboreum* and *T. dioica* are also important components of local diets with *T. dioica* being a popular vegetable and *R. arboreum* blossoms being used in locally made drinks and food preparations. Numerous pharmacological actions including antidiabetic, antioxidant, hepatoprotectiveand anti-inflammatory properties are supported by their rich phytochemical composition which include flavonoids, alkaloids, saponins and essential fatty acids. In line with the current interest in functional foods and plant-based health treatments, these plants show promise in bridging the gap between food/ nutrition and medicine. To better incorporate these botanicals into health and nutrition frameworks and improve public wellness and food security, future research will focus on standardizing preparations, guaranteeing safety and investigating clinical applications.

However, key gaps remain, including limited clinical evidence, lack of standardized extraction and formulation methods and insufficient long-term safety assessments. Addressing these gaps through well-designed clinical trials, mechanistic studies and formulation optimization will be essential for translating traditional uses into validated therapeutic and nutraceutical applications.

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Authors' contributions

In this review article, M conducted the literature review, analyzed phytochemical and pharmacological data and played the lead role in drafting the manuscript. AM and BP contributed to the critical evaluation of the content and helped to refine the conclusion. All authors reviewed and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflicts of interest to declare.

Ethical issues: None

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