ejpmr, 2025, 12(9), 61-66

EUROPEAN JOURNAL OF PHARMACEUTICAL AND MEDICAL RESEARCH

www.ejpmr.com

SJIF Impact Factor

Review Article

ISSN (O): 2394-3211

ISSN (P): 3051-2573

TRAPA NATANS: A COMPREHENSIVE REVIEW OF ITS PHYTOCHEMISTRY, PHARMACOLOGICAL, AND THERAPEUTIC POTENTIAL

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Article Received on 02/07/2025 **Article Revised on 22/07/2025** **Article Accepted on 13/08/2025**

ABSTRACT

Trapa natans L., commonly known as water chestnut, is an aquatic plant widely distributed in Asia, Africa, and Europe, valued for its nutritional, medicinal, and ecological importance. Traditionally used in Ayurvedic, Unani, and folk medicine, *T. natans* has been employed for managing ailments such as diarrhea, dysentery, urinary disorders, inflammation, and oxidative stress. This review comprehensively compiles and analyzes current literature on its phytochemical composition, pharmacological activities, and therapeutic potential. The plant is rich in bioactive compounds, including flavonoids, tannins, phenolic acids, saponins, and carbohydrates, which contribute to its diverse biological effects. Pharmacological studies have demonstrated antioxidant, antimicrobial, anti-inflammatory, antidiabetic, hepatoprotective, and anticancer activities in various experimental models. Despite its promising pharmacological profile, gaps remain in clinical validation, standardization of extracts, and elucidation of molecular mechanisms. This review highlights the need for advanced research to establish *T. natans* as a scientifically validated source of nutraceuticals and therapeutic agents, bridging the gap between traditional knowledge and modern pharmacology.

KEYWORDS: *Trapa natans*, water chestnut, phytochemistry, pharmacology, therapeutic potential, medicinal plant.

1. INTRODUCTION

Trapa natans L., commonly known as water chestnut or water caltrop, is a floating-leaved aquatic plant belonging to the family Lythraceae. Widely distributed across Asia, Africa, and Europe, this species holds significant nutritional, medicinal, and ecological value. The plant has been cultivated for centuries, not only as a food source but also as an integral component of traditional healing systems, particularly Ayurveda and Unani medicine. In various cultures, *T. natans* fruits and seeds have been utilized to manage ailments such as diarrhea, dysentery, urinary tract infections, inflammation, and general debility.[1]

Phytochemical investigations have revealed that *T. natans* is a rich source of bioactive compounds, including flavonoids, tannins, phenolic acids, saponins, and essential minerals, which contribute to its diverse biological activities. Experimental studies have demonstrated promising pharmacological effects, such as antioxidant, antimicrobial, anti-inflammatory, antidiabetic, hepatoprotective, and anticancer properties. These findings underscore its potential as a nutraceutical and as a candidate for drug discovery.

Despite its widespread traditional use and emerging pharmacological evidence, scientific knowledge on *T. natans* remains fragmented, with limited efforts to integrate ethnobotanical wisdom, chemical profiling, and therapeutic validation. Moreover, most current studies are confined to in vitro and preclinical models, with a notable absence of standardized extracts, clinical evaluations, and molecular mechanism elucidation.

This review aims to provide a comprehensive and critical analysis of the available literature on *Trapa natans*, focusing on its phytochemistry, pharmacological activities, and therapeutic potential. By bridging traditional knowledge with modern scientific research, this work seeks to highlight the significance of *T. natans* in the context of nutraceutical development and natural product-based drug discovery, while also identifying research gaps that warrant further investigation.[2]

2. Botanical and Ethnobotanical Profile

2.1 Taxonomy and Classification

- **Kingdom:** Plantae
- **Clade:** Angiosperms
- **Order:** Myrtales
- **Family:** Lythraceae

- **Genus:** *Trapa*
- **Species:** *Trapa natans* L.

Common synonyms include *Trapa bicornis* and *Trapa bispinosa*. The plant is popularly known as water chestnut, water caltrop, and by several vernacular names: *Singhara* (Hindi), *Paniphal* (Bengali), *Makhana* (though botanically different, often confused in trade), and *Ling Kok* (Chinese).[3]

2.2 Morphological Description

Trapa natans is an annual, floating-leaved hydrophyte rooted in the mud of shallow lakes, ponds, and slow-moving rivers. The stem is flexible and submerged, bearing finely divided underwater leaves. The floating leaves are arranged in a rosette at the water surface, rhomboid to diamond-shaped, with serrated margins and inflated petioles that aid buoyancy. The inconspicuous white flowers bloom singly, above water, during summer. The fruits are hard, woody drupes with two to four sharp horns, enclosing a starchy seed that serves as the edible portion.[4]

2.3 Geographical Distribution and Cultivation

Native to Eurasia and Africa, *T. natans* has a wide distribution in tropical, subtropical, and temperate zones. It is cultivated extensively in India, China, Bangladesh, and parts of Southeast Asia for its edible seeds. In certain regions of North America, it is considered an invasive species due to its rapid vegetative growth and ability to form dense mats that alter aquatic ecosystems. Cultivation generally involves sowing seeds in shallow, nutrient-rich water bodies, with harvest occurring in late summer to autumn when the fruits mature.[5]

2.4 Traditional and Folk Uses

The use of *Trapa natans* in traditional medicine dates back centuries.

- **Ayurvedic Medicine:** Seeds are considered cooling, nutritive, and restorative, prescribed for treating diarrhea, dysentery, urinary tract disorders, and seminal weakness.
- **Unani Medicine:** Used as a tonic for the liver and spleen, and as a remedy for sexual debility.
- **Chinese Traditional Medicine:** Believed to aid digestion, stop diarrhea, and detoxify the body.
- **Folk Remedies:** In rural India and Bangladesh, powdered seeds are consumed for general weakness, while the fruit shell is sometimes applied externally for wound healing.

Beyond medicinal use, *T. natans* seeds are consumed fresh, boiled, roasted, or dried and milled into flour for making snacks, sweets, and beverages, offering both nutritional and functional food benefits.[6]

3. Nutritional Composition

The edible seeds of *Trapa natans* are valued as a nutrient-dense food source, providing a balanced mix of macronutrients and micronutrients. They are consumed in fresh, boiled, roasted, or dried forms, and the flour derived from dried seeds is widely used in traditional snacks and fasting foods in South Asia.[7]

3.1 Macronutrients

Trapa natans seeds are predominantly rich in carbohydrates, primarily in the form of starch, making them an important source of dietary energy. The seeds also provide moderate amounts of protein, with a favorable amino acid profile, and low levels of fat.

Typical composition (per 100 g of dried seeds)[8]

- **Carbohydrates:** 65–75%
- **Protein:** 8–12%
- **Fat:** 0.5–1.5%
- **Dietary Fiber:** 6–10%
- **Moisture:** 8–12%

3.2 Micronutrients

The seeds are a good source of minerals and vitamins essential for maintaining health.

- **Minerals:** Calcium, phosphorus, potassium, magnesium, iron, and trace amounts of zinc and manganese.
- **Vitamins:** Vitamin B-complex (notably thiamine, riboflavin, and niacin) and small amounts of vitamin C.

Calcium and phosphorus contribute to bone health, while potassium supports cardiovascular function and electrolyte balance.[9]

3.3 Bioactive Nutrients

Apart from basic nutrition, *T. natans* seeds also contain functional components such as polyphenols, flavonoids, and tannins, which exhibit antioxidant properties. The presence of these bioactives bridges the nutritional and therapeutic significance of the plant, making it both a food and a potential nutraceutical.[10]

3.4 Functional and Dietary Uses

Due to its low-fat content and high starch concentration, *T. natans* is recommended in diets for convalescence, fasting, and certain therapeutic regimens. In Ayurvedic practice, seed flour is used in formulations for digestive health and as a general tonic. The gluten-free nature of the flour also makes it suitable for individuals with gluten intolerance or celiac disease.[11]

4. Phytochemistry

Phytochemical investigations of *Trapa natans* have revealed a diverse array of primary and secondary metabolites that contribute to its nutritional value and therapeutic properties. Both the seeds and other plant parts, including leaves, stems, and fruit pericarps, contain bioactive constituents responsible for a range of pharmacological activities.[12]

4.1 Primary Metabolites

Primary metabolites serve as essential nutrients and building blocks for plant growth and human nutrition. In *T. natans* seeds, the predominant primary metabolites include.

- **Carbohydrates:** Mainly starch (amylose and amylopectin) contributing to high energy value.
- **Proteins:** Containing essential amino acids such as lysine, leucine, and phenylalanine.
- **Lipids:** Low total lipid content, with traces of unsaturated fatty acids.[12]

4.2 Secondary Metabolites

Secondary metabolites are primarily responsible for the pharmacological effects of *T. natans*. Key groups include.

- **Flavonoids:** Such as quercetin, kaempferol, and their glycosides, known for antioxidant and anti-inflammatory effects.
- **Tannins:** Predominantly hydrolysable tannins (e.g., ellagitannins) with antimicrobial and astringent properties.
- **Phenolic Acids:** Including gallic acid, ellagic acid, and ferulic acid, exhibiting potent antioxidant activities.
- **Saponins:** Contributing to immunomodulatory and cholesterol-lowering effects.
- **Alkaloids:** Detected in small amounts, potentially influencing neurological and antimicrobial actions.[13]

4.3 Plant Parts and Their Phytochemical Distribution

- **Seeds:** Rich in starch, polyphenols, flavonoids, and minerals.
- **Fruit Pericarp:** Contains high levels of tannins and phenolic acids.
- **Leaves and Stems:** Flavonoids, phenolic acids, and chlorophyll pigments.[14]

4.4 Analytical Techniques for Phytochemical Profiling

Various modern and classical techniques have been employed to isolate and identify phytoconstituents of *T. natans*.

- **Chromatography:** High-Performance Liquid Chromatography (HPLC), Gas Chromatography–Mass Spectrometry (GC-MS), Thin Layer Chromatography (TLC).
- **Spectroscopy:** UV–Vis spectrophotometry, Fourier Transform Infrared (FTIR) spectroscopy, Nuclear Magnetic Resonance (NMR).
- **Mass Spectrometry:** Liquid Chromatography–Mass Spectrometry (LC-MS) for precise molecular characterization.

The diversity of these phytoconstituents provides a strong biochemical basis for the pharmacological activities of *T. natans*, supporting its traditional uses and opening new avenues for drug development.[15]

5. Pharmacological Activities

Experimental research on *Trapa natans* has revealed a wide range of pharmacological activities, many of which correlate strongly with its phytochemical composition. Most studies have been conducted using in vitro assays and in vivo animal models, with results supporting its traditional medicinal uses.[16]

5.1 Antioxidant Activity

Several studies have demonstrated that extracts of *T. natans* possess significant free radical scavenging activity. The high content of phenolic acids (gallic acid, ellagic acid) and flavonoids (quercetin, kaempferol) contributes to inhibition of oxidative stress by neutralizing reactive oxygen species (ROS) and enhancing endogenous antioxidant enzymes such as superoxide dismutase (SOD) and catalase. This activity plays a protective role against oxidative damage in cells and tissues.[17]

5.2 Antimicrobial and Antiviral Activity

Methanolic and aqueous extracts of *T. natans* have shown inhibitory effects against Gram-positive and Gram-negative bacteria, including *Escherichia coli*, *Staphylococcus aureus*, and *Pseudomonas aeruginosa*. The tannins and phenolic acids disrupt microbial cell walls and interfere with enzyme systems. Preliminary studies also suggest possible antiviral effects, although detailed mechanism-based investigations are limited.[18]

5.3 Anti-inflammatory and Analgesic Activity

In vivo studies have reported that seed and pericarp extracts reduce inflammation induced by carrageenan and other agents in experimental models. The mechanism is linked to suppression of pro-inflammatory mediators such as TNF-α, IL-6, and COX-2, attributed mainly to flavonoids and saponins. Analgesic activity has also been observed, indicating potential in pain management.[19]

5.4 Antidiabetic Activity

Ethanolic extracts of T. natans seeds have demonstrated hypoglycemic effects in streptozotocin-induced diabetic rats. Mechanisms include enhancement of insulin secretion, improvement in glucose tolerance, and inhibition of α-amylase and α-glucosidase enzymes. Polyphenols and saponins are believed to contribute to these effects.

5.5 Hepatoprotective Activity

Animal studies have indicated that *T. natans* extracts protect the liver from chemically induced damage, such as that caused by carbon tetrachloride (CCl_4). Protection is attributed to antioxidant effects, stabilization of hepatocyte membranes, and regulation of liver enzymes (ALT, AST, ALP).[20]

5.6 Anticancer Potential

Preliminary in vitro cytotoxicity assays have shown that *T. natans* extracts can inhibit the growth of certain

cancer cell lines, possibly through induction of apoptosis and cell cycle arrest. Phenolic compounds and flavonoids may exert anti-proliferative effects via modulation of signaling pathways, though further mechanistic and clinical studies are needed.

5.7 Other Reported Activities

- **Immunomodulatory:** Enhancement of immune response via stimulation of lymphocyte proliferation.
- **Antidiarrheal:** Reduction of intestinal motility and fluid secretion in experimental models.
- **Nephroprotective:** Potential protection against kidney damage caused by oxidative stress.

The breadth of pharmacological activities observed in *T. natans* supports its value as both a traditional remedy and a candidate for modern drug development. However, most data come from laboratory studies; rigorous clinical evaluation remains a critical next step.[21]

6. Toxicity and Safety Profile

Despite its long history of use as a food and traditional remedy, scientific evaluation of the toxicity and safety profile of *Trapa natans* is relatively limited. Available studies suggest that the plant is generally safe when consumed in dietary amounts, but high doses or prolonged use of concentrated extracts may pose risks.

6.1 Acute Toxicity

Animal model studies have reported that aqueous and ethanolic extracts of *T. natans* seeds exhibit no observable toxic effects up to doses of 2000 mg/kg body weight, as per OECD guidelines. No mortality or significant behavioral changes were noted, indicating a relatively high safety margin for short-term consumption.[22]

6.2 Sub-acute and Chronic Toxicity

Limited data are available on prolonged exposure. Some studies suggest that repeated high-dose administration of tannin-rich extracts may cause gastrointestinal discomfort and reduced nutrient absorption due to tannin–protein interactions. Chronic toxicity studies are scarce, and further investigations are required to establish no-observed-adverse-effect levels (NOAEL).

6.3 Allergenic Potential

There are no well-documented cases of allergic reactions to *T. natans* seeds; however, individuals sensitive to tannins or polyphenols in other foods may experience mild gastrointestinal irritation.[23]

6.4 Safe Dosage Considerations

- **Dietary use:** Regular consumption of fresh or boiled seeds in moderate quantities is considered safe.
- **Therapeutic extracts:** Should be standardized for active constituents and dosed based on preclinical toxicity data until clinical safety trials are available.

6.5 Potential Contraindications

- Excessive intake of raw seeds may cause digestive discomfort due to tannin content.
- Caution is advised in individuals with severe iron deficiency anemia, as tannins may inhibit iron absorption.
- Pregnant and lactating women should use standardized extracts only under medical supervision, due to lack of comprehensive safety data.

Overall, *T. natans* appears to have a favorable safety profile when consumed as part of the diet. Nevertheless, systematic toxicological evaluations and human clinical safety assessments are essential before its development into standardized nutraceutical or pharmaceutical products.[24]

7. Therapeutic Potential and Applications

The phytochemical richness and broad pharmacological profile of *Trapa natans* position it as a promising candidate for therapeutic, nutraceutical, and functional food applications. Its bioactive constituents — including flavonoids, tannins, phenolic acids, and saponins — have been linked to antioxidant, anti-inflammatory, antimicrobial, antidiabetic, and hepatoprotective effects, providing a scientific basis for many of its traditional uses.

7.1 Nutraceutical Applications

The seeds of *T. natans* are already consumed widely as a dietary component, especially during fasting periods in South Asia, due to their high energy value and gluten-free nature. Standardized extracts enriched in polyphenols could be developed as.

- **Antioxidant supplements** to counter oxidative stress-related disorders.
- **Metabolic health products** aimed at regulating blood sugar and lipid levels.
- **Functional beverages or fortified foods** for general wellness.[25]

7.2 Pharmaceutical Potential

Given its documented pharmacological activities, *T. natans* has potential in drug discovery and development for.

- **Metabolic disorders:** As an adjunct therapy in diabetes and dyslipidemia management.
- **Hepatic disorders:** As a hepatoprotective agent against toxin-induced damage.
- **Inflammatory diseases:** As a natural anti-inflammatory and analgesic.
- **Cancer therapy support:** As a source of cytotoxic and apoptosis-inducing agents for integrative oncology approaches (pending further validation).

7.3 Traditional Medicine Integration

The use of *T. natans* in Ayurveda, Unani, and Chinese medicine could be modernized through:

- Standardization of herbal formulations.

- Validation of dosage regimens through preclinical and clinical studies.
- Combination with other medicinal plants for synergistic effects.

7.4 Functional Food Development

The flour derived from dried seeds can be incorporated into bakery products, energy bars, and health drinks, offering a gluten-free alternative with added therapeutic benefits. Polyphenol-rich fractions could also be used to fortify foods targeted at cardiovascular and metabolic health.[26]

7.5 Cosmeceutical Potential

The antioxidant and antimicrobial activities of *T. natans* suggest possible applications in skincare formulations aimed at anti-aging, wound healing, and acne prevention.

By bridging its ethnomedicinal history with modern scientific evidence, *T. natans* can be positioned as a multipurpose plant with applications spanning the food, pharmaceutical, and cosmetic industries. However, commercial exploitation should be guided by rigorous safety assessments, sustainable harvesting practices, and intellectual property protection for traditional knowledge.[7]

8. Research Gaps and Future Directions

Although *Trapa natans* has been extensively used in traditional medicine and shows a promising pharmacological profile in preclinical studies, significant gaps remain before it can be fully validated as a modern therapeutic or nutraceutical agent.[15]

8.1 Lack of Standardized Extracts

Most pharmacological studies have used crude extracts without standardization for active constituents. The absence of standardized preparations makes it difficult to compare results and reproduce findings across laboratories. Development of well-characterized extracts is crucial for quality assurance and regulatory compliance.

8.2 Limited Mechanistic Studies

While bioactivity assays demonstrate antioxidant, anti-inflammatory, and other effects, detailed molecular mechanism studies are scarce. Investigating signaling pathways, gene expression changes, and target interactions will enhance understanding of the plant's therapeutic actions.

8.3 Insufficient Clinical Evidence

Current data on *T. natans* are largely limited to in vitro and animal studies. Well-designed human clinical trials are necessary to confirm safety, efficacy, optimal dosage, and long-term effects.[4]

8.4 Toxicological Data Deficiency

Although acute toxicity appears low, chronic toxicity, genotoxicity, and reproductive toxicity studies are lacking. These assessments are essential for nutraceutical and pharmaceutical product development.

8.5 Sustainable Cultivation and Conservation

In some regions, *T. natans* faces overharvesting due to increasing demand, while in others, it is considered invasive. Sustainable cultivation practices, habitat management, and germplasm conservation strategies are needed to ensure availability without ecological harm.[20]

8.6 Potential for Value-Added Products

Opportunities exist to explore *T. natans* in.

- Nanoformulations to enhance bioavailability.
- Synergistic polyherbal combinations.
- Green extraction techniques for eco-friendly bioactive recovery.

Addressing these gaps through interdisciplinary research will help transform *T. natans* from a traditional aquatic plant into a scientifically validated, globally recognized resource for health and wellness.[22]

9. CONCLUSION

Trapa natans, an aquatic plant with deep ethnobotanical roots, embodies a unique convergence of nutritional richness and therapeutic potential. Traditionally valued in Ayurveda, Unani, and other folk systems of medicine, it has been employed for the management of gastrointestinal ailments, urinary disorders, inflammation, and general debility. Modern phytochemical investigations reveal a diverse spectrum of bioactive compounds including flavonoids, tannins, phenolic acids, and saponins that underpin its broad pharmacological activities.

Preclinical studies substantiate its antioxidant, antimicrobial, anti-inflammatory, antidiabetic, hepatoprotective, and anticancer properties, providing a scientific basis for its historical uses. However, the translation of these findings into clinical practice remains limited due to a lack of standardized extracts, well-defined molecular mechanisms, and robust human trials.

With the growing global demand for plant-based therapeutics and functional foods, *T. natans* holds promise as a multipurpose resource in nutraceutical, pharmaceutical, and cosmeceutical industries. Realizing this potential will require interdisciplinary efforts encompassing phytochemistry, pharmacology, toxicology, clinical research, and sustainable cultivation. Bridging traditional wisdom with modern science can transform *T. natans* from a locally valued aquatic plant into a globally recognized agent for health and wellness.

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