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Review Article

The Nutritional Powerhouse: A Comprehensive Review of *Nelumbo Nucifera* (Lotus Plant) and Its Therapeutic Benefits

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Abstract
Nelumbo nucifera (Lotus) belongs to the monogeneric family *Nelumbonaceae.* It is found primarily in Asia, the Americas, and Oceania. It is common in different countries, such as the Indian lotus, the Chinese water lily, and the sacred lotus. It has been used and cultivated as a vegetable because of its unique phytomorphology for more than 2000 years. The plant has different parts, i.e., leaf, stem, rhizome, seed, stamen, seed pod, etc. The leaf, seed, and rhizome of lotus are used for the treatment of different diseases, such as smallpox, leucoderma, hematemesis, dysentery, pharyngopathy, pectoralgia, spermatorrhoea, cough, hemoptysis, epistaxis, hematuria, metrorrhagia, hyperlipidemia, fever, cholera, hepatopathy, and polydipsia. Different phytochemicals, including steroids, flavonoids, alkaloids, and phenolic acids, are present in lotus extracts and play beneficial roles in skin whitening and in the treatment of cancer, hepatic steatosis, hyperglycemia, and Alzheimer's disease. The presence of a steroidal triterpenoid in the rhizome extract was used due to its antidiabetic and anti-inflammatory properties. The condensed tannins of lotus may precipitate proteins and reduce foam formation, serving in the rumen. It can serve as a potential alternative to chemical anthelmintics for controlling gastrointestinal parasitic nematodes. This study explores the potential applications of *N. nucifera* in contemporary medicine and sustainable agriculture, highlighting the need for additional investigations to better understand its medicinal properties and environmental advantages. It also identifies critical research gaps, such as the need for clinical trials, dosage standardization, and detailed toxicological studies, to translate traditional wisdom into evidence-based applications.

Keywords: *Nelumbo nucifera*, lotus plant, nutritional benefits, therapeutic properties, herbal medicine, antioxidant, dietary fiber

1. Introduction
Nelumbo nucifera, commonly referred to as Lotus, is a perennial aquatic plant that is largely cultivated in Asian countries. It has been identified as a sacred Indian lotus, lotus, or Chinese water lily, and is widely recognized as a nutritional and medicinal plant (Ullah et al. 2018). Its medicinal attributes have been documented in Ayurvedic and traditional Chinese medicine, and it has been used in Asian cultures for more than 2,000 years (Kakar et al. 2023; Paudel and Panth 2015). The monogeneric family *Nelumbonaceae* comprises two extant species of *Nelumbium nucifera* (Asian lotus) and *Nelumbium lutea* (American lotus) (Lin et al. 2019). Asian lotus blooms in Asia and the northern parts of Oceania and has red, pink, or white flowers. The American lotus is distributed across eastern and southern North America and in the northern regions of South America, and has yellow flowers. *N. nucifera*, in particular, stands out within the realm of socio-cultural studies for its versatile applications and rich symbolic meaning (Ullah et al. 2018).

Lotus is extensively grown in China, India, Japan, Pakistan, and other Asian countries (Ayesha, Siddiqui, and Saeed 2022). China is considered a major cultivator of *N. nucifera*, often referred to as lotus, kamala, or padma, in India (Mehta et al. 2013). It has been grown for food, medicine, and religious purposes for three millennia. Various sects associate it with diverse spiritual beliefs. Lotus is associated with serenity and tranquility (Ahmed et al. 2019). In Pakistan, it is cultivated in the upper Sindh and lower Punjab districts (Shad et al. 2011). Locally, it is known as Nadru or Bursanda.

Various parts of the lotus have historically been utilized in several traditional Chinese and Indian medicines (Ayurveda). The rhizome has economic significance since it contains compounds that have a positive impact on human health (Yang et al. 2024).

According to previous studies, the lotus rhizome includes alkaloids that help address symptoms of arrhythmia, sunstroke, fever, diarrhea, dysentery, disorientation, and stomach disorders. Psychopharmacological, anti-inflammatory, antioxidant, antipyretic, diuretic, hypoglycemic, immunomodulatory, and antidiarrheal are included in pharmacological effects (Chen, Zhu, and Guo 2019).

Lotus seed pods are occasionally used to support the function of the heart in traditional medicine. Cough can be effectively treated with a mixture of seed powder and honey. Traditional Chinese medicine incorporates lotus seed embryos for the treatment of cardiovascular ailments, neurological disorders, sleep deprivation, elevated temperatures with irritability, and arrhythmias (Mukherjee et al. 2009).

Despite its long history of use, a comprehensive and critical review integrating its detailed nutritional profile with its mechanistically explained pharmacological effects is lacking. This review aims to fill that gap by systematically evaluating the scientific evidence behind the traditional uses of *N. nucifera*, with a specific focus on its role as a nutritional powerhouse, and to identify future research directions for its application in modern medicine and functional foods.

2. Morphological Characteristics

The lotus plant is characterized by its distinct parts: roots, rhizomes, leaves, flowers, and seeds (Figure 1). The roots are adventitious and anchor the plant in the muddy bottoms of water bodies. The rhizome is a modified stem that grows horizontally underwater, serving as a storage organ and a means of asexual propagation. Leaves are large, peltate, and can be either floating or emergent, growing up to 60 cm in diameter on long petioles that elevate them above the water surface. The flowers are showy, can reach 20 cm in diameter, and are borne on solitary stalks above the leaves. They are typically pink, white, or yellow. The fruit is an aggregate of nuts embedded in a characteristic conical receptacle (the seed pod). Lotus ecotypes are broadly classified as temperate or tropical. The temperate ecotype has an expanded rhizome and a dormant period, while the tropical ecotype has a whip-shaped rhizome and a prolonged vegetative and flowering phase (Ayesha, Siddiqui, and Saeed 2022; Min et al. 2019).

2.1. Rhizome

Lotus plants produce rhizomes, which are modified stems that facilitate asexual propagation. These rhizomes form in submerged environments and start to expand after sprouting, developing floating leaves at their nodes. As they grow to approximately 10–20 cm in length, the rhizomes begin to swell, accumulating carbohydrates. Stolon, initial swelling, middle swelling, and later swelling are the stages of development. This development process is influenced by photoperiod and temperature, although the specific molecular processes involved are mostly unclear (Min et al. 2019; Trang, Thao, and Hong 2019).

2.2. Leaves

The leaves of lotus plants are of two types: large and circular, ranging from 20 to 90 cm in diameter. They can either be aerial or floating. These leaves have an abruptly pointed tip, are attached to a

Figure 1: **Parts of *Nelumbo nucifera* plants.**

stalk, and are smooth-edged with a bluish-green hue. Aerial leaves are strongly cupped, whereas floating leaves are flat. They have prominent veins and are initially leathery but become thin and fragile upon drying. According to reports, the flavonoids found in lotus leaves have the ability to control blood cholesterol levels, have antibacterial and antioxidant qualities, prevent atherosclerosis, and reduce liver damage (Zhu et al. 2015).

2.3. Seeds

Lotus seeds are ovoid nuts, approximately 1-1.5 cm long, with a hard, impermeable pericarp. They are located within the cavities of the funnel-shaped seed pod. The seed consists of two large, fleshy cotyledons and a central green embryo, known as the plumule (Bangar et al. 2022).

3. Bioactive Compounds and Pharmacological Properties

The therapeutic potential of *N. nucifera* is attributed to a diverse array of bioactive compounds present in its different parts. This section details the phytochemical composition and the evidence-based pharmacological activities of these compounds.

3.1. Phytochemical Composition of Rhizome

Lotus rhizomes are abundant in bioactive compounds. Modern phytochemical profiling using LC-MS and GC-MS has identified over 170 distinct compounds, including lipids, nucleotides, organic acids, and a particularly rich profile of polyphenols such as coumarins and flavonoids (J. Liu et al. 2023). The nutritional composition per 100 g of fresh rhizome includes 83.80% water, 0.11% fat, 2.70% crude protein, 9.25% starch, and 0.80% fiber. It also contains vitamins such as thiamine (0.22 mg), riboflavin (0.6 mg), niacin (2.10 mg), and ascorbic acid (1.5 mg), along with minerals including calcium, potassium, and iron (Yamini et al. 2019; Mukherjee et al. 2009). Notably, the methanol extract of rhizomes contains betulinic acid, a pentacyclic triterpenoid (Ahmed et al. 2019). Traditionally, rhizomes have been recommended to soften hemorrhoids, and for chronic dyspepsia, and diarrhea (Mehta et al. 2013).

3.2. Phytochemical Composition and Properties of Leaves

Phytochemical analysis of lotus leaves reveals a rich content of alkaloids and flavonoids. GC-MS studies

Phytochemical analysis of lotus leaves reveals a rich content of alkaloids and flavonoids. GC-MS studies on leaf extracts have identified several benzylisoquinoline alkaloids, including nuciferine, pronuciferine, and armepavine (Ma et al. 2023). The leaves are also rich in flavonoids such as quercetin, kaempferol, and their glycosides (e.g., hyperin, isoquercetin) (Zhu et al. 2015). These compounds are responsible for the observed lipid-lowering, anti-inflammatory, antioxidant, and anti-obesity properties of lotus leaves. For instance, the total flavonoids from lotus leaves have been shown to inhibit pancreatic lipase, α-amylase, and α-glucosidase enzymes *in vitro*, suggesting a mechanism for their anti-obesity and antidiabetic effects (S. Liu et al. 2013). *In vivo*, these extracts increased high-density lipoprotein cholesterol while lowering triglycerides, low-density lipoprotein cholesterol, and total cholesterol in high-fat diet-fed rats (Velusami, Agarwal, and Mookambeswaran 2013).

3.3. Nutritional and Bioactive Composition of Seeds

Lotus seeds are valued as a healthy food, rich in proteins, amino acids, unsaturated fatty acids, and minerals such as calcium, magnesium, zinc, and iron. They contain various bioactive compounds, including the alkaloid liensinine, which has demonstrated efficacy in treating arrhythmia in experimental models (Mehta et al. 2013). Contrary to the initial statement, seed extracts (at doses of 0.1–30 mg/mL *in vitro*) have been shown to protect against, not induce, ischemia in rat hearts, with an optimal anti-ischemic dose of 3 mg/m (Ahmed et al. 2019).

4. Cultivation and Harvesting

4.1. Temperature and Environmental Requirements

The lotus thrives at altitudes up to 2000 m above sea level, though optimal growth occurs at lower elevations. It requires temperatures above 15°C for at least six months to grow well, with optimal root growth occurring at temperatures greater than 20°C. Higher temperatures promote root branching and flower development but can also increase susceptibility to fungal diseases such as Fusarium wilt. Lotus is a sun-loving plant and is sensitive to cold and drought (Rana, Hooda, and Sharma 2017). Key cultivation parameters include a water depth of 20-50 cm and a thick, clay-rich mud substrate.

4.2. Harvesting

The timing and methodology of harvesting rhizomes depend on environmental factors, specific varieties, and cultivation purposes. Before harvesting, ponds are generally emptied, and the roots are manually dug; however, an automatic harvesting system is being developed in Japan. Rhizome that are cream or light brown in color and measure between 60–120 cm in length and 6–9 cm in diameter is considered ready for harvest. It typically takes 120–150 days after planting for the roots to reach this size. Post-harvest, the rhizomes require careful handling to prevent bruising and are often stored in water or a cool, humid environment to maintain freshness (Rana, Hooda, and Sharma 2017).

5. Detailed Pharmacological Effects

5.1. Anti-inflammatory Effects

Fermented lotus root (FLR) is a functional food that can be used to alleviate inflammatory illnesses. Notably, linoleic acid (LA) is one of the main components of *N. nucifera*. However, the connection between LA and inflammation is still debatable (Fritsche 2015). The mechanisms through which FLR and LA have anti-inflammatory effects are under investigation, but *in vitro* studies suggest they may involve the suppression of pro-inflammatory cytokines like TNF-α and IL-6 in LPS-induced RAW 264.7 macrophages (Kim et al. 2020). Significant anti-inflammatory efficacy was also demonstrated by the rhizome extract and by betulinic acid.

5.2. Anti-obesity Effects

As mentioned in section 3.2, the anti-obesity effects of lotus leaf flavonoids are primarily attributed to the inhibition of key digestive enzymes (pancreatic lipase, α-amylase) and the modulation of lipid metabolism. *In vivo* studies in high-fat diet models have confirmed these effects, showing reduced cholesterol accumulation in the liver and improved serum lipid profiles (Velusami, Agarwal, and Mookambeswaran 2013).

5.3. Antidiabetic and Hypoglycemic Effects

N. nucifera is a significant source of herbal medicine for diabetes. Its hypoglycemic effects are mediated through multiple mechanisms. In non-obese diabetic mice, lotus plumule polysaccharide (LPPS) protected pancreatic islet β cells and reduced inflammation (Liao and Lin 2011). Furthermore, an ethanol extract of the rhizome significantly reduced blood glucose levels in streptozotocin-induced diabetic rats, potentially by regulating GLUT4 receptor activity or insulin secretion (Pipil et al. 2023). It is important to note that most evidence is derived from animal models, and human clinical trials are needed.

5.4. Hepatoprotective Effects

5.4.1. Effect on Hepatotoxicity

One study revealed how varying doses of lotus extract affected Mz (Mancozeb)-induced oxidative stress and hepatotoxicity. The extract ameliorated Mz-induced body weight loss, histological damage, and oxidative stress markers. This hepatoprotection is likely achieved by upregulating phase II detoxification enzymes and scavenging reactive oxygen species (ROS) (Nuchniyom et al. 2023).

The extract itself, at the tested doses, did not show any observed toxicity, indicating a wide safety margin.

5.4.2. Effect on Hepatic Steatosis

Polyphenol-rich plants like lotus have been investigated for nonalcoholic fatty liver disease (NAFLD). Specifically, a polyphenolic extract from lotus root alleviated hepatic steatosis in obese diabetic db/db mice. The proposed mechanism involves the downregulation of lipogenic genes and the activation of AMP-activated protein kinase (AMPK), a key regulator of energy metabolism (Tsuruta et al. 2011).

5.5. Anticancer Properties

The potential of *N. nucifera* as an anticancer agent has been thoroughly studied recently. Fractions and pure chemicals extracted from various sections of the lotus plant have shown strong anticancer effects. For instance, the alkaloids nuciferine and liensinine, and the flavonoids quercetin and kaempferol, have demonstrated pro-apoptotic and anti-proliferative activities in various cancer cell lines, including breast, lung, and liver cancers (Singh et al. 2024). These effects are mediated through mechanisms such as the induction of apoptosis, inhibition of angiogenesis, and manipulation of signaling pathways like PI3K/Akt and MAPK.

5.6. Neuroprotective and Psychopharmacological Properties

Compounds from *N. nucifera* show promise for neurodegenerative diseases like Alzheimer's disease (AD). *In vitro* and *in vivo* studies indicate that extracts from stamens, seeds, and petals exhibit acetylcholinesterase (AChE) and beta-secretase (BACE-1) inhibitory activities. A methanolic extract of stamens was found to increase cAMP production and dopaminergic neurotransmission. Furthermore, a hydroethanolic extract of blossoms improved memory and reduced oxidative stress in stress-induced rat models (Temviriyanukul et al. 2020). These findings suggest a neuroprotective role, though clinical validation is required.

5.7. Dermatological Properties

5.7.1. Skin Whitening

Lotus seed extract has been shown to exhibit antioxidant and anti-tyrosinase activities. Skin-whitening potential is linked to the inhibition of tyrosinase, the key enzyme in melanin synthesis, by bioactive compounds such as polyphenols present in the extract (Moon et al. 2023).

5.7.2. Anti-aging

One of the main flavonoids in lotus stamens, kaempferol-3-O-robinobioside (Kae-3-Rob), has been identified as a potential anti-aging agent through combined computational and experimental methodologies. *In vitro* enzyme-

Table 1. Representative Nutritional Composition of Different Lotus Parts.

Plant Part	Key Nutritional Components	Notable Bioactive Compounds	Analytical Method
Rhizome	Starch (9.25%), Protein (2.70%), Dietary Fiber (0.80%), Vitamin C (1.5 mg/100g), K, Ca, Fe	Betulinic acid, Polyphenols, Coumarins	HPLC, LC-MS, AAS
Leaves	---	Alkaloids (Nuciferine, Armepavine), Flavonoids (Quercetin, Kaempferol glycosides)	GC-MS, HPLC
Seeds	Protein (~18%), Fat (~2%), Minerals (Mg, Zn, Mn, K)	Alkaloids (Liensinine), Proanthocyanidins, Flavonoids	ICP-MS, HPLC

K: Potassium, Ca: Calcium, Fe: Iron, Mg: Magnesium, Zn: Zinc, Mn: Manganese, ICP-MS= Inductively Coupled Plasma–Mass Spectrometry, GC-MS: Gas Chromatography–Mass Spectrometry, HPLC: High-Performance Liquid Chromatography, AAS: Atomic Absorption Spectroscopy.

based tests confirmed that Kae-3-Rob significantly inhibits tyrosinase and collagenase, enzymes involved in skin pigmentation and wrinkle formation, respectively (Nutho and Tungmunnithum 2023). These *in vitro* results warrant further investigation in skin models or clinical studies.

5.8. Sleep-promoting Properties

Compared with control mice, mice given 150 mg/kg lotus rhizome water extract (LE) orally presented a substantial 24% increase in sleep duration. This effect was mediated through the GABAergic system, as LE increased GABA concentration in the brain and the expression of GABAA receptors, and its sleep-promoting effects were antagonized by flumazenil (Ahn et al. 2022). The active compounds responsible, such as nuciferine, are under investigation. Human trials are necessary to establish clinical relevance.

6. Culinary and Industrial Uses

6.1. Culinary Uses

Lotus root is a versatile ingredient in Asian cuisine, valued for its mild, slightly sweet flavor and crunchy texture. It is used in stir-fries, soups, salads, and as a deep-fried chip. Nutritionally, it provides complex carbohydrates, dietary fiber, and essential minerals like potassium and phosphorus. Lotus seeds are also consumed and are a rich source of protein, unsaturated fats, and minerals. They contain specific bioactive compounds like liensinine and flavonoids, which remain relatively stable in processed foods such as lotus seed paste, mooncakes, and noodles (Thanushree, Sudha, and Crassina 2017). Lotus seed milk has been explored as a plant-based alternative for puddings and baked goods (Shahzad et al. 2021).

6.2. Industrial Uses

Lotus rhizome starch is effective for a variety of industrial formulations. Dual-modification (e.g., cross-linking followed by oxidation using agents like sodium trimetaphosphate and sodium hypochlorite at concentrations of 1-3%) enhances its pasting properties and thermal stability, making it suitable for food applications requiring high stability (Sukhija, Singh, and Riar 2017). In the food industry, lotus leaf extracts are used as natural antioxidants to improve the oxidative and color stability of meat products (Wang et al. 2021).

7. Nutritional Composition

The nutritional profile of *N. nucifera* varies significantly depending on the plant part, geographical location, and analytical method. A consolidated summary of key nutrients is presented in Table 1.

8. Conclusion and Future Perspectives

In conclusion, *N. nucifera* is a versatile plant with significant nutritional and medicinal value. This review has detailed its rich composition of bioactive compounds such as the alkaloids nuciferine and liensinine, and flavonoids like quercetin and kaempferol, which underpin its evidence-based pharmacological activities, including antioxidant, antidiabetic, hepatoprotective, and anti-inflammatory effects. However, several critical gaps remain. Future research should focus on: (1) Conducting well-designed human clinical trials to validate the efficacy and safety observed in preclinical studies; (2) Standardizing extraction methods and dosages for therapeutic applications; (3) Performing comprehensive toxicological and pharmacokinetic studies of isolated bioactive compounds; (4) Exploring the synergistic effects of lotus phytochemicals in complex mixtures; and (5) Further investigating its potential in managing non-communicable diseases like NAFLD, diabetes, and cancer. Addressing these areas will be crucial for translating the traditional wisdom surrounding the sacred lotus into evidence-based nutraceutical and pharmaceutical applications.

Conflict of Interest

The authors declare no competing interests.

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Availability of Data and Materials

All data generated or analyzed during this study are included in this published article. Data can be available on demand.

Ethics Approval and Consent to Participate

Not applicable

Authors' Contributions

MR designed the study, NA, NF, ZA, MS, FN, and MR did most of the data search and acquisition. All authors read and approved the final manuscript.

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