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THERAPEUTIC POTENTIAL OF *LEMNA MINOR* IN KWASHIORKOR: A COMPREHENSIVE REVIEW

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Abstract

Kwashiorkor is a severe form of protein-energy malnutrition predominantly affecting infants and young children in developing countries. It is mainly caused by inadequate protein intake and is associated with edema, muscle wasting, fatty liver, impaired immunity, growth retardation, and increased susceptibility to infections. Nutritional deficiencies associated with kwashiorkor contribute significantly to morbidity and mortality among children worldwide. Conventional management primarily involves nutritional rehabilitation and correction of protein deficiency; however, there is increasing interest in identifying sustainable and affordable nutritional sources with therapeutic benefits. *Lemna minor*, commonly known as duckweed, is a small free-floating aquatic plant belonging to the family Araceae. The plant possesses high nutritional value due to its rich protein content, essential amino acids, vitamins, minerals, flavonoids, phenolic compounds, and antioxidants. Scientific studies have demonstrated that *Lemna minor* exhibits various pharmacological activities including antioxidant, anti-inflammatory, antimicrobial, hepatoprotective, immunomodulatory, and nutritional enhancement properties. Owing to its high protein content and balanced amino acid profile, *Lemna minor* has gained attention as a potential natural nutritional supplement for the management of protein-energy malnutrition disorders such as kwashiorkor. The present review highlights the nutritional composition, phytochemical constituents, pharmacological activities, and therapeutic significance of *Lemna minor* in the management of kwashiorkor. The review also discusses its potential role in nutritional rehabilitation, immune enhancement, oxidative stress reduction, and future prospects in the development of plant-based nutritional therapies.

Keywords: *Lemna minor*, Duckweed, Kwashiorkor, Protein-energy malnutrition, Nutritional therapy, Antioxidant activity.

Introduction

Malnutrition remains one of the most serious global health problems, particularly among children in developing and underdeveloped countries (Das *et al.*, 2015). Protein-energy malnutrition is a major nutritional disorder caused by inadequate intake of proteins and calories, leading to impaired growth, weakened immunity, and increased susceptibility to infections. Among the various forms of protein-energy malnutrition, kwashiorkor is considered one of the most severe and life-threatening conditions (Stephenson *et al.,* 2000). The disorder commonly affects infants and young children after weaning, especially when diets are deficient in protein but relatively adequate in carbohydrates. Kwashiorkor is characterized by edema, muscle wasting, enlarged fatty liver, anemia, skin lesions, growth retardation, and compromised immune function (Michael *et al.,* 2022).

The pathogenesis of kwashiorkor is complex and involves protein deficiency, oxidative stress, micronutrient deficiencies, impaired antioxidant defense mechanisms, and inflammatory responses (Bunker and Pandey, 2021). Inadequate protein intake reduces plasma albumin levels, leading to fluid accumulation and edema. Deficiency of essential amino acids further impairs tissue repair, enzyme synthesis, immune responses, and metabolic functions. In addition, oxidative stress and free radical generation contribute to cellular damage and organ dysfunction in malnourished individuals. Children suffering from kwashiorkor often experience recurrent infections, delayed development, and increased mortality risk (Briend *et al.*, 2014).

Current management of kwashiorkor mainly focuses on nutritional rehabilitation, correction of electrolyte imbalance, treatment of infections, and gradual restoration of protein and energy intake (Brewster *et al.*, 1997). However, the high cost of nutritional supplements, limited food availability, and poor accessibility in resource-limited regions create significant challenges in effective management. Consequently, there is growing interest in exploring affordable, sustainable, and nutrient-rich plant sources that can serve as alternative nutritional therapies for protein-energy malnutrition (Scherbaum and Furst, 2000).

Among various aquatic plants, *Lemna minor*, commonly known as duckweed, has emerged as a promising nutritional and therapeutic resource (Jaimes *et al.,* 2024). *Lemna minor* is a small free-floating freshwater plant widely distributed in ponds, lakes, and slow-moving water bodies across tropical and temperate regions. The plant is known for its rapid growth rate, high adaptability, and exceptional nutritional composition. Duckweed contains high levels of proteins, essential amino acids, carbohydrates, vitamins, minerals, dietary fibers, and bioactive phytochemicals, making it a valuable source of nutrition.

The protein content of *Lemna minor* is particularly significant, often ranging between 25–45% of dry weight, depending on environmental and cultivation conditions. The plant also contains essential amino acids such as lysine, methionine, threonine, valine, leucine, and tryptophan, which are important for growth and tissue repair (Chakrabarti *et al.,* 2018). In addition to its nutritional value, *Lemna minor* contains flavonoids, phenolic compounds, carotenoids, chlorophylls, and antioxidants that contribute to its pharmacological activities. Scientific studies have reported antioxidant, anti-inflammatory, antimicrobial, hepatoprotective, immunomodulatory, and hypolipidemic properties of the plant.

Due to its high protein content and balanced nutritional profile, *Lemna minor* has gained considerable attention as a sustainable alternative protein source for human nutrition and animal feed (Miltko *et al.*, 2024). The plant may help improve nutritional status, enhance immune function, reduce oxidative stress, and support recovery in malnourished individuals. Its rapid cultivation, low production cost, and environmental sustainability further enhance its potential as a therapeutic nutritional supplement in regions affected by food insecurity and malnutrition.

Therefore, the present review aims to provide a comprehensive overview of the nutritional composition, phytochemical constituents, pharmacological activities, and therapeutic potential of *Lemna minor* in the management of kwashiorkor. The review also highlights its possible mechanisms of action, health benefits, and future perspectives in nutritional and pharmaceutical research.

Plant Profile of *Lemna minor*

Lemna minor is a small aquatic flowering plant belonging to the family Araceae. It is commonly known as duckweed because it serves as food for ducks and aquatic birds (Van der Plas, 1972). The plant is widely distributed in freshwater environments such as ponds, lakes, marshes, and slow-flowing rivers. *Lemna minor* consists of tiny floating green fronds with one or more simple roots extending into the water. It reproduces rapidly through vegetative budding and is considered one of the fastest-growing plants in the world.

Taxonomically, the plant belongs to Kingdom Plantae, Division Magnoliophyta, Class Liliopsida, Order Alismatales, Family Araceae, Genus Lemna, and Species *Lemna minor*. Due to its simple structure and high adaptability, the plant can thrive in nutrient-rich aquatic environments.

Nutritional Composition of *Lemna minor*

Lemna minor possesses exceptional nutritional value and is considered a rich source of proteins, amino acids, carbohydrates, vitamins, minerals, and bioactive compounds. The protein content of the plant is remarkably high and comparable to several conventional protein-rich foods. The presence of essential amino acids such as lysine, methionine, leucine, isoleucine, valine, and threonine makes the plant nutritionally valuable for growth and tissue maintenance.

The plant also contains vitamins including vitamin A, vitamin C, vitamin B-complex, and vitamin E. Important minerals such as calcium, potassium, magnesium, phosphorus, iron, zinc, and manganese are present in significant amounts (Akram *et al.*, 2020). In addition, *Lemna minor* contains dietary fibers, chlorophyll, carotenoids, flavonoids, and phenolic compounds that contribute to its antioxidant and therapeutic properties. The balanced nutritional composition of *Lemna minor* makes it a promising dietary supplement for combating protein deficiency and micronutrient malnutrition.

Phytochemical Constituents

Phytochemical investigations of *Lemna minor* have revealed the presence of numerous bioactive compounds responsible for its pharmacological activities (Shaheen *et al.*, 2025). The plant contains flavonoids, phenolic acids, tannins, alkaloids, terpenoids, carotenoids, chlorophylls, glycosides, and saponins. Polyphenolic compounds and flavonoids possess strong antioxidant activity and help protect cells against oxidative stress.

The plant also contains bioactive pigments such as lutein and beta-carotene, which contribute to antioxidant and immune-enhancing effects. Phenolic compounds present in *Lemna minor* exhibit anti-inflammatory and

antimicrobial activities (Al-Snafi, 2019). These phytochemicals collectively contribute to the medicinal and nutritional significance of the plant.

Pharmacological Activities of *Lemna minor* (Seferli *et al.*, 2024)

Table: Pharmacological Activities of *Lemna minor*

S. No.	Pharmacological Activity	Bioactive Constituents Involved	Mechanism of Action	Therapeutic Significance in Kwashiorkor
1	Antioxidant Activity	Flavonoids, phenolic compounds, carotenoids, chlorophyll	Neutralization of reactive oxygen species and reduction of oxidative stress	Protects tissues from oxidative damage and improves recovery in malnourished individuals
2	Anti-inflammatory Activity	Phenolics, flavonoids, tannins	Inhibition of inflammatory mediators such as prostaglandins and cytokines	Reduces inflammation and tissue injury associated with malnutrition and infections
3	Immunomodulatory Activity	Proteins, vitamins, minerals, antioxidants	Enhancement of immune cell function and immune responses	Improves resistance against infections and enhances immune function
4	Hepatoprotective Activity	Antioxidants, carotenoids, phenolic compounds	Prevention of lipid peroxidation and protection of hepatocytes	Protects against fatty liver and hepatic dysfunction associated with kwashiorkor
5	Nutritional Enhancement Activity	Proteins, essential amino acids, vitamins, minerals	Restoration of protein balance and improvement of metabolic functions	Supports growth, tissue repair, and nutritional rehabilitation
6	Antimicrobial Activity	Flavonoids, tannins, alkaloids	Inhibition of microbial growth and disruption of microbial cell membranes	Helps prevent infections commonly observed in malnourished children
7	Antidiarrheal Activity	Tannins, phenolic compounds	Reduction of intestinal inflammation and fluid secretion	Helps manage diarrhea and improves nutrient absorption
8	Growth Promoting Activity	Essential amino acids, proteins, micronutrients	Enhancement of protein synthesis and cellular growth	Supports physical and developmental growth in children

9	Hypolipidemic Activity	Polyphenols, flavonoids	Reduction of lipid accumulation and regulation of lipid metabolism	Helps prevent fatty liver and improves metabolic health
10	Tissue Regeneration Activity	Amino acids, vitamins, antioxidants	Promotion of cellular repair and regeneration	Accelerates healing of damaged tissues and improves recovery
11	Anti-anemic Activity	Iron, folic acid, vitamins	Enhancement of hemoglobin synthesis and red blood cell production	Helps correct anemia associated with protein-energy malnutrition
12	Gastroprotective Activity	Flavonoids, mucilage, antioxidants	Protection of gastric mucosa and reduction of oxidative injury	Improves gastrointestinal health and nutrient utilization
13	Detoxifying Activity	Chlorophyll, antioxidants	Elimination of toxins and reduction of oxidative metabolites	Supports liver function and overall metabolic health
14	Micronutrient Supplementation Activity	Calcium, iron, zinc, magnesium, vitamins	Restoration of micronutrient deficiencies	Improves physiological and biochemical functions in malnourished individuals
15	Energy Enhancing Activity	Carbohydrates, proteins, essential nutrients	Improvement of metabolic energy production	Reduces weakness and fatigue associated with kwashiorkor

Therapeutic Potential of *Lemna minor* in Kwashiorkor

The therapeutic potential of *Lemna minor* in kwashiorkor is mainly associated with its high nutritional value and pharmacological activities. Protein deficiency is the primary cause of kwashiorkor, and the rich protein content of *Lemna minor* may help correct protein imbalance and improve plasma albumin levels. Essential amino acids present in the plant support muscle growth, tissue repair, and enzyme synthesis.

Antioxidant compounds present in *Lemna minor* help reduce oxidative stress and cellular damage associated with severe malnutrition (Abdel-Gawad *et al.*, 2020). The anti-inflammatory and immunomodulatory activities further contribute to improved recovery and protection against infections. Vitamins and minerals present in the plant help correct micronutrient deficiencies commonly observed in kwashiorkor patients.

The plant may also improve gastrointestinal health and nutrient absorption, thereby enhancing overall nutritional status (Majeed *et al.*, 2025). Due to its rapid growth and low cultivation cost, *Lemna minor* represents a sustainable and affordable nutritional source for resource-limited populations.

Advantages of *Lemna minor* as a Nutritional Supplement

Lemna minor offers several advantages as a nutritional supplement in the management of kwashiorkor and protein-energy malnutrition (Pal and Bose, 2025). The plant is rich in high-quality proteins and essential amino acids, making it an effective natural protein source. It grows rapidly in aquatic environments and requires minimal agricultural resources, making it economically feasible and environmentally sustainable.

The plant also contains important vitamins, minerals, antioxidants, and dietary fibers that contribute to overall health improvement. Compared to animal protein sources, *Lemna minor* is cost-effective, eco-friendly, and suitable for large-scale cultivation. Its use may help address food insecurity and nutritional deficiencies in developing countries (Sosa *et al.*, 2024).

Limitations and Future Perspectives

Despite its promising nutritional and therapeutic properties, several limitations exist regarding the clinical application of *Lemna minor* in kwashiorkor management. Limited clinical studies are available to validate its efficacy and safety in human subjects. Standardization of cultivation conditions, harvesting methods, and processing techniques is necessary to ensure consistent nutritional quality (Takacs *et al.*, 2025).

Further investigations are required to identify specific bioactive compounds, evaluate long-term safety, and determine optimal dosage regimens. Advanced research involving clinical trials, pharmacokinetic studies, and formulation development is essential to establish the therapeutic potential of *Lemna minor* in malnutrition management.

Future research should also focus on the development of fortified nutritional formulations, nutraceutical products, and functional foods based on *Lemna minor*. Integration of the plant into community nutrition programs may provide sustainable solutions for combating protein-energy malnutrition and food insecurity.

Conclusion

Lemna minor is a nutritionally rich aquatic plant with significant therapeutic potential in the management of kwashiorkor and protein-energy malnutrition. The plant contains high levels of proteins, essential amino acids, vitamins, minerals, and bioactive phytochemicals that contribute to its nutritional and pharmacological properties. Scientific studies have demonstrated antioxidant, anti-inflammatory, hepatoprotective, immunomodulatory, and nutritional enhancement activities of the plant.

The high protein content and balanced nutritional composition of *Lemna minor* make it a promising natural supplement for correcting protein deficiency and improving nutritional status in malnourished individuals. Its affordability, rapid growth, and environmental sustainability further enhance its importance as an alternative nutritional resource. However, further scientific and clinical investigations are necessary to validate its efficacy, safety, and therapeutic applications in the management of kwashiorkor.

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