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Bioactive Phytochemicals and Nutritional Significance of Makhana (Euryale ferox): A Health Perspective systematic review

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ABSTRACT

Despite its significant potential in human diets, the aquatic seed Euryale ferox (makhana), which is historically consumed in South Asia, is still neglected in terms of nutrition. Along with vital micronutrients like calcium, magnesium, potassium, and phosphorus, it is distinguished by a favourable macronutrient profile that includes complex carbs, high-quality plant protein, dietary fibre, and a low-fat content. Apart from its nutritional worth, Euryale ferox has a variety of bioactive phytochemicals, including as flavonoids, phenolic compounds, and antioxidant components, which enhance its health benefits. Its significance in preventive nutrition is supported by experimental research that points to possible functions in glycaemic management, oxidative stress modulation, cardiovascular protection, and metabolic health. However, its undervaluation as a functional food resource has been exacerbated by low knowledge, poor integration into contemporary food systems, and insufficient scientific consolidation. Euryale ferox has significant prospects for value addition, functional food development, and nutrition security in light of the increased interest in plant-based nutrition, sustainable diets, and traditional cuisines. Standardized compositional analysis, bioavailability of bioactive substances, clinical validation o f health benefits, and integration into evidence-based dietary regimens should be the main areas of future study.

Keywords: *Euryale ferox, Makhana, Nutritional significance, Bioactive phytochemicals, functional foods, Future perspectives*

1. Introduction

The aquatic species Makhana (Euryale ferox), often referred to as fox nut or Gorgon nut, belongs to the Nymphaeaceae family and has long been prized as a food source in South and East Asia. E. ferox seeds have been ingested from prehistoric times, according to archaeobotanical data, indicating the plant's deep cultural and nutritional roots throughout Asia. India is the largest producer worldwide of makhana, with over 90% of global cultivation taking place there, particularly in the floodplain regions of Bihar, despite the fact that it is naturally found throughout tropical and subtropical freshwater habitats in nations like China, Japan, Korea, Russia, Bangladesh, Nepal, and India. About 80–90% of India's total production comes from Bihar alone, especially from districts like Darbhanga, Madhubani, Purnia, Saharsa, and Katihar; smaller-scale cultivation takes place in West Bengal, Assam, Manipur, Tripura, Odisha, Madhya Pradesh, Rajasthan, and Uttar Pradesh.

Makhana seeds are widely recognized for their high carbohydrate content (around 70–77%), significant plant protein content (about 9–10%), dietary fibre, extremely low-fat content, and vital minerals including calcium, phosphorus, iron, magnesium, and trace elements. With caloric density and protein quality that support energy supply and nutritional balance, this compositional profile offers a low-fat, nutrient-dense food source. In addition to macronutrients and micronutrients, Euryale ferox has bioactive phytochemicals such as flavonoids, phenolic acids, and antioxidant substances that have been linked to anti-inflammatory, metabolic regulation, and free-radical

scavenging properties. These characteristics generate interest because to their possible applications in preventative nutrition and functional meals, underscoring makhana's worth beyond just nourishment.

Traditional Chinese Medicine (TCM) and Ayurveda are two examples of traditional medical systems that have used the therapeutic properties of Euryale ferox's seeds, leaves, and roots. It has traditionally been used as an aphrodisiac and to treat conditions including diarrhoea, inflammation, and kidney issues. In the last few decades, there has been a growing interest in studying the pharmacological potential of medicinal plants due to their rich phytochemical composition. Euryale ferox is reported to contain a variety of bioactive chemicals that contribute to its medicinal properties, including as flavonoids, alkaloids, saponins, tannins, and phenolic compounds.

The World Health Organization (WHO) highlights diet diversification as a tactic to fight non-communicable diseases, while international organizations like the United Nations Food and Agriculture Organization (FAO) stress the significance of diversifying food systems with nutrient-rich, underutilized crops to improve global nutrition security. Makhana is becoming more widely recognized in these frameworks, but it is still not well-represented in official dietary standards.

Recent government announcements have emphasized the promotion of makhana production and marketing, including proposals for a dedicated Makhana Board in Bihar to strengthen supply chains and research, and the Geographical Indication (GI) tag for Mithila Makhana has elevated its global identity as a value-added export commodity. As Makhana, one of the neglected traditional foods, is a nutrient-dense, sustainable crop with great potential to enhance health-oriented food systems and nutrition security. These actions are indicative of growing institutional support in India. These programs, along with the National Research Centre for Makhana's expanded research mandates, indicate a renewed focus on improving cultivation techniques, boosting nutritional utilization, and increasing the crop's integration into both domestic and foreign markets.

FOXNUT TAXONOMY (MAKAHANAS)

Although the term "foxnut" can refer to a number of plant species, Euryale ferox, the water lily, is most commonly associated with it. The Euryale ferox taxonomy is displayed below:

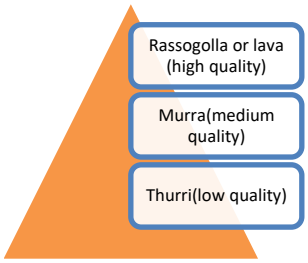
Table: 1 Fox nut Taxonomy representation

Kingdome	**Plantae**
Phylum	Plantae Angiosperms (flowering plants)
class	Eudicots
Order	Nymphaeales
Family	Nymphaeaceae (water lily family)
Genus	Euryale
Species	Euryale ferox

Source: (Manharan Anant et.al., 2022)

Foxnut, fox nut, gorgon nut, makhana, and lotus seed are common names for Euryale ferox. The seeds of this plant are widely used in gourmet foods and traditional remedies throughout Asia, particularly in China and India. They are valued for their medicinal properties and nutritional advantages.

Types of Makhana (Fox nut) according to quality



Source: (Rathod et.al., 2023)

Figure: 1 illustration showing quality of Fox nut

Makhanas Nutritional Aspects

Composition

The nutritional composition of fox nut as carbohydrates, proteins, moisture, minerals, fat, phosphorus, calcium, and iron, along with a smaller quantity of ascorbic acid, phenol, and sugar, are the components of Euryale ferox, according to nutritional research done to identify its contents.

Carbohydrates are the most abundant of these components, which are found in varying levels.

Table: 2 The constituents of Euryale ferox are mentioned

Constituents	Amount (%)
Carbohydrate	76.9
Protein	9.7
Mineral	0.5
Fat	0.1
phosphorus	0.9
Calcium	0.02
iron	0.004
Moisture	12.8

Source: (Shukla et. el., 2024)

Makhana is an aquatic cash crop that is low in fat and high in protein and carbohydrates. Makhana has a high market value, however 1.72% of its 3.46% output is wasted. A commercial surplus accounts for around 80% of makhana output. The raw makhana has 76.9% carbohydrates, 12.8% moisture, 9.7% protein, 0.9% phosphorus, 0.5% minerals, 0.1% fat, 0.02% calcium, and 0.0014% iron. Puffed makhana is composed of 84.9% carbs, 4% moisture, 9.5% protein, and 0.5% fat. Makhana had enormous medicinal benefits and helped the cotton industry. Makhana promoted proper treatment for the reproductive, circulatory, respiratory, and digestive systems. According to biochemical analysis, makhana seed has a high protein content of 15.6% and a fat level of 1.36%, as shown in Table 2. Raw and puffed makhana contain 362 and 328 kcal per 100 grams, respectively. The makhana's high protein and fat content makes it similar to almonds, walnuts, cashew nuts, and coconuts.

The makhanas kernel included sixteen distinct types of amino acids. The essential amino acid index (EAAI), biological value (BV), and chemical score (CS) of makhana are similar to those of fish. Compared to eggs, makhana contains a higher protein and amino acid content (g/16 g N) of arginine, alanine, and tyrosine. Makhana's apparent digestibility (CE), true digestibility (TU), and net protein utilization (NPU) are 69.1, 89.3, and 49.3, respectively. Makhana's NPU, TU, and CE were lower than those of soybean, egg, and cow milk. The makhana is high in macronutrients and micronutrients and an excellent source of minerals.The trace elements Cu, Na, Ca, Fe, and Mg as well as N, P, and K are found in large quantities in the vegetative section of makhana, according to several studies. The elevated P, Fe, and Zn concentration is a result of the muddy field conditions. Vitamins A and C, which vary from 62.23 to 63.84 IU/g and 0.18% to 0.20%, respectively, are also highly concentrated in makhana. Makhana's exceptional nutritional value and uniqueness have led to a daily increase in its market value. Black diamond is another term for makhana seed. Makhana contains a high proportion of carbohydrates (78%), which have starchy proportions.

The makhana has a lot of minerals and barely 0.1% fat. Makhana has 362 kcal per 100g, but popped makhana only contains 328 kcal per 100g. Makhana has a very poor biological value, however its seed has a high ratio of leucine to isoleucine. Compared to other dry fruits like walnuts, cashew nuts, and almonds, fox nuts are more nutritious. Despite having a lower percentage level (10–12%) than other cereals, makhana protein was more nutritious than many plant- and animal-based diets. The different mineral compositions of Makhana according to size are shown in Table 2. It was found that the raw and puffed edible makhana pieces had essential amino acid indices (EAAI) of 93% and 89%, respectively. Compared to the percentages for rice (83%), wheat (65%), and Bengal, these are greater for grain (81.55%), soy bean (85.6%), amaranth (57.5%), and breast milk. Fish (85.2%), cow's milk (80.8%), mutton (87.24%), and fish (89.5%). From the 77% starch content, amylose and amylopectin were recovered. The former made up 25% of the total.

Makhana in Indian Dietary Patterns

Makhana (Euryale ferox) has a particular place in traditional Indian diets, especially in the country's eastern, northern, and northeastern areas. It is most frequently eaten as a dry-roasted snack, either plain or mildly seasoned, making it a well-liked low-fat substitute for fried snacks among both urban and rural communities. Makhana is frequently used in household meals and celebratory cuisines in areas like Bihar, Uttar Pradesh, West Bengal, Assam, and portions of Madhya Pradesh. While makhana flour is increasingly employed in flatbreads, porridges, and infant-feeding formulas, it is still commonly used in traditional recipes including makhana kheer, vegetable curries, sabzi, raita, and laddus. Because of its digestibility and satiety value, makhana is a permitted, energy-supplying snack that is especially popular during religious fasting periods. Makhana's use has increased into ready-to-eat snacks, morning cereals, bakery goods, and nutraceutical formulations in recent years due to urban dietary shifts, demonstrating its increasing appeal across a variety of socioeconomic strata. Makhana's versatility within Indian diets and its potential to encourage healthy eating habits through both traditional and contemporary food systems are highlighted by these changing consumption patterns.

Figure: 2 Demonstration different makhana recipe

Source: Author own Work

The antioxidant properties of foxnuts(makhanas)

The antioxidant activity of foxnuts linked to diseases like proteinuria inhibition or diabetic nephropathy is the most notable effect of makhana. Foxnut (Euryale ferox Salisb) extracts exhibit greater rates of radical scavenging behaviour, decreasing power, and are a potent antioxidant because they lower lipid peroxidation when tested using DPPH, TEAC, and CAT (catalase) SOD (superoxide dismutase) activity. It also protects against H2O2-induced apoptosis, increases the activity of many antioxidant enzymes, and enhances cell viability.

Foxnuts are a significant natural source of antioxidants and may be used as dietary supplements, functional foods, and drugs for diabetes and hyperlipidaemia. They contain kaempferol, a flavonoid with anti-inflammatory and anti-free radical qualities. Foxnuts contain anti-aging qualities. The most powerful antioxidants have been demonstrated to be amino acids, which may function as a combatant, eliminate free radical intermediates, and halt chain reactions. Leucine, isoleucine, methionine, cysteine, arginine, and glutamine are the most significant amino acids found in foxnuts. The amino acids arginine and methionine are precursors to creatine, which is necessary for healthy skin, nails, and hair. Healthy skin requires creatine, which is derived from arginine and methionine.

Furthermore, creatine is essential for the body's cell metabolism. The formation of connective tissue, cells, and skin metabolism is made possible by the energy that creatine gives cells. Taurine, which is made from cysteine, reduces the effects of diabetes on cells. Arginine increases blood flow by producing nitric oxide in the tissue and restoring the veins' and arteries' elasticity. Other amino acids that support the body's growth and development include proline and iso-leucine.

Anti-diabetic properties of Fox-nut (Makhanas)

Many numbers of metabolic illnesses and many dangerous diseases caused by a number of metabolic problems, including improper protein, lipid, and glucose metabolism, which are caused by a mix of genetic and environmental factors. Makhana's complex carbohydrate structure and low

sugar content give it a low glycaemic index (GI). This leads to moderate glucose release and delayed digestion, which helps avoid post-prandial blood glucose spikes—a crucial dietary tactic for managing diabetes.

Nutraceutical and Medicinal Properties (Makhanas)

The edible E. ferox seeds both raw and popped edible are traded and exported. Carbohydrates are the most prevalent of these components, which are present in different amounts, according to nutritional study done to determine its constituents. Because it is nearly fatless, it is a highly sought-after food item in nations where obesity is a concern. Makhana is utilized because of its nutritious qualities. It has a high index of essential amino acids (EAAI), 89–93%, 78% starch-based carbs, 0.5% minerals, and a modest percentage of proteins (10–12%). Makhana's high index of essential amino acids, which is higher than other staple meals, reveals its unique nature. Makhana has a range of phytochemical components, including Ca (0.02), P (0.9), and Fe (0.0014). It contains high levels of ascorbic acid, phenol, and sugar. Even in extremely low-sodium soil, the plant may absorb enough sodium. The caloric value of raw makhana seeds is 362 kcal/100g, whereas that of pops is 328 kcal/100g. Makhana seeds have a low biological value of about 55, which may be explained by their greater leucine to isoleucine ratios. It contains kaempferol, which is known to have antioxidant, anti-inflammatory, and anti-aging properties. It helps with cleansing, strengthens the heart, and improves renal function. It is commonly used in Ayurvedic and Unani medicine to treat hypertension, arthritis, and insomnia.

Makhana as a Source of Phytochemical and Bioactive Substances

Makhana (Euryale ferox Salisb.) has drawn more and more attention from scientists as a nutritious diet enhanced with a variety of phytochemical and bioactive components that go beyond basic nourishment. Its biological action is attributed to the presence of phenolic acids, flavonoids, tannins, alkaloids, and glycosides, according to phytochemical studies. These substances have strong antioxidant activity, mainly via scavenging free radicals and blocking oxidative stress pathways. The total phenolic and flavonoid content of E. ferox has been linked to its antioxidant ability, indicating its significance in reducing oxidative damage linked to chronic non-communicable disorders.

Makhana's potential as a functional food component is further highlighted by experimental research that suggest its bioactive compounds may have anti-inflammatory, anti-diabetic, cardioprotective, and Reno protective benefits. Resistant starch, dietary fiber, and polyphenols boost metabolic health by improving lipid metabolism and glycaemic response. Euryale ferox may also have neuroprotective and anti-aging qualities due to its antioxidant and anti-stress capabilities, according to both traditional use and new research. Compared to other functional foods, makhana's bioactive potential is still understudied despite these encouraging qualities. Its broader applicability is hampered by a lack of clinical validation, variations in phytochemical content brought on by processing techniques, and a lack of bioavailability data. However, Euryale ferox is a prospective option for nutraceutical research, dietary supplements, and preventive nutrition methods due to the increased interest in plant-based bioactive and sustainable food systems. To support its health claims and make it easier to include it into evidence-based dietary programs, more research on standardized phytochemical profiling and human intervention trials is necessary.

Makhana as a Functional Food

Makhana (Euryale ferox Salisb.) is increasingly being recognized as a functional food because of its special blend of bioactive components that promote health and adequate nutrition. Makhana, which is naturally low in fat and gluten-free, is a staple of Indian diets and offers complex carbohydrates, dietary fibre, moderate-quality plant protein, and important minerals. Its importance in supplying daily energy needs and preserving metabolic balance is supported by this advantageous nutritional profile, especially in populations with dietary limitations or a higher risk oflifestyle-related diseases. Makhana has a variety of bioactive phytochemicals, including as flavonoids and phenolic compounds, which provide anti-inflammatory and antioxidant qualities in addition to basic nutrients. These bioactive enhance its functional value in the prevention and treatment of non-communicable illnesses including diabetes, cardiovascular disorders, and obesity by modulating oxidative stress, glycaemic response, and lipid metabolism. Further promoting gut health and postprandial glucose management are dietary fibre and resistant starch.

Furthermore, makhana can be used in therapeutic diets, geriatric nutrition, and maternal health programs due to its excellent digestibility, reduced glycaemic load, and advantageous mineral content. Euryale ferox presents significant potential for value-added food items, nutraceutical formulations, and health-oriented dietary treatments, given the increasing consumer demand for plant-based and sustainable functional foods. However, to support its functional claims and maximize its use in evidence-based nutrition regimens, more clinical research and standardized processing techniques are needed.

Makhana as a Nutritional Supplement

Makhana (Euryale ferox Salisb.) has become a potential natural nutritional supplement because of its excellent digestibility, functional bioactive, and nutrient density. Makhana, which is typically eaten whole, is being

investigated more and more for use as a supplement in powdered and processed forms. In addition to being low in fat and naturally gluten-free, it offers complex carbs, dietary fibre, moderate-quality plant protein, and important minerals including calcium, magnesium, potassium, and phosphorus. Its use as a plant-based supplement for micronutrient improvement and energy provision is supported by these characteristics.

Its additional benefit is further increased by the inclusion of bioactive phytochemicals, such as flavonoids and phenolic acids, which have anti-inflammatory and antioxidant properties. These characteristics may improve metabolic health and reduce oxidative stress, especially in populations with high nutritional needs or a higher risk of chronic illnesses. Because of their simple digestion and long-lasting energy release, makhana-based supplements have demonstrated potential value in clinical recovery diets, sports nutrition, maternity and child health, and geriatric nutrition. Recent developments in food processing have made it possible to include makhana into protein blends, powdered formulations, fortified snacks, and nutraceutical capsules, increasing its acceptability and convenience. Nevertheless, issues including inconsistent nutritional content, little bioavailability information, and inadequate clinical validation still exist. In order to establish Euryale ferox as an evidence-based nutritional supplement within preventative and therapeutic nutrition frameworks, future research should concentrate on standardized processing methods, dose-response assessment, and human intervention trials.

Makhana as a Nutraceutical

Makhana (Euryale ferox Salisb.) has generated interest as a possible nutraceutical because of its bioactive phytochemicals and high nutritional makeup. In addition to being low in fat and gluten-free, the seeds are a good source of complex carbohydrates, plant-based protein, dietary fiber, and important minerals, making them appropriate for a variety of dietary requirements. Beyond its basic nutritional composition, Euryale ferox has antioxidant components, flavonoids, and phenolic compounds with anti-inflammatory, cardioprotective, anti-diabetic, and neuroprotective qualities that support functional health benefits. Its growth as a nutraceutical element for preventive nutrition and control of lifestyle-related illnesses, such as oxidative stress, metabolic syndrome, and cardiovascular risks, is supported by these bioactive components. Makhana's use in health-focused formulations has increased thanks to recent processing advancements that have made it possible to produce powders, capsules, fortified snacks, and functional drinks. The need for additional study to create evidence-based nutraceutical uses of Euryale ferox in human health is highlighted by the lack of clinical validation and standardization of bioactive content despite encouraging experimental and preclinical findings.

Future Prospects

The rich nutritional content and bioactive potential of makhana (Euryale ferox) and makhana-based products have drawn more attention in recent years. In addition to plant protein, dietary fiber, and antioxidant phytochemicals all of which are frequently lacking in contemporary Indian diets—makhana is an excellent source of important minerals including calcium, magnesium, potassium, and phosphorus. Including makhana and its value-added products in daily meals can enhance preventative nutrition, improve bone and metabolic health, and treat micronutrient deficiencies, especially in women, children, and the elderly. Significant commercial prospects are also presented by the rising popularity of ready-to-eat meals and health-conscious snacks in India. Processing facilities that make kheer mixes, roasted seeds, makhana flour, snacks, morning cereals, and fortified drinks may increase economic value, create jobs, and open up new markets. Additionally, makhana's nutrients and bioactive components may be isolated and made into powders, pills, or capsules, allowing it to be sold as a dietary supplement or nutraceutical for a variety of health advantages.

Conclusion

In the entire world, India particularly Bihar, is the global leader in the production of Euryale ferox (Makhana, Fox nut, Prickly water lily). The majority of people in Bihar rely on this crop's production for their livelihood. Due to its many ayurvedic qualities, this plant has been utilized since the Ayurvedic era. It is used in Indian culture to make a variety of foods, including curries, Makhana Chapatti, Makhana Kalakand, Makhana Barfi, and Makhana Pakora.

A food rich in nutrients and bioactive, makhana (Euryale ferox) has significant potential to promote nutrition security and improve human health. Its seeds, which are naturally low in fat and gluten-free, offer a balanced blend of complex balance of carbs, plant-based protein, dietary fibre, and vital minerals. Furthermore, secondary metabolites such as polyphenols, sequineolignans, tocopherols, cyclic dipeptides, cerebrosides, glucosyl sterols, and triterpenoids are abundant in major sections of this plant. Its importance as a functional food, supplement, and nutraceutical is highlighted by the presence of various bioactive phytochemicals, such as flavonoids and phenolic compounds, which provide notable hypoglycaemic, cardioprotective, antibacterial, anticancer, anti-depression, antioxidant hepatoprotective, anti-inflammatory, and metabolic health benefits. Makhana is still neglected in contemporary food systems despite its historic use and growing body of scientific data, and there is no systematic clinical confirmation of its health-promoting benefits.

To maximize its use in therapeutic treatments and preventative nutrition, future research should concentrate on

standardized phytochemical profiling, bioavailability studies, clinical trials, and the creation of value-added formulations. A sustainable way to improve public health, encourage dietary variety, and advance functional and nutraceutical uses of underutilized traditional foods is to include Euryale ferox into modern diets and food products.

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