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A systematic review of *Lemna minor*: exploring potential utilization

Uma revisão sistemática da *Lemna minor*: explorando os potenciais de utilização

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RESUMO

Lemna minor, popularmente conhecida como lentilha-d'água, é uma espécie de macrófita aquática encontrada em corpos d'água doce ou de baixa salinidade, protegidos de fortes ventos e correntes, geralmente formando populações densas que flutuam na superfície dos corpos d'água. A presente revisão discute o conhecimento disponível sobre o uso da lentilha-d'água (*L. minor*) nas diversas áreas do conhecimento científico, destacando seus principais avanços e aplicações, bem como identificando lacunas e campos ainda pouco explorados relacionados à espécie. Entre 1972 e 2024, 341 publicações obtidas nas bases de dados Web of Science e Scopus foram exportadas e analisadas por meio da ferramenta Bibliometrix para a definição e a análise crítica dos principais autores, periódicos e países. Os artigos envolvendo *L. minor* são publicados em sete áreas do conhecimento: toxicidade, biorremediação, fatores de crescimento, genética, produção de energia, agricultura e suplementação animal. Foram registrados os três artigos mais citados em cada área. Os dados revistos sugerem que a tecnologia para o cultivo de plantas aquáticas é simples e barata. A lentilha-d'água pode absorver, decompor e reabsorver nutrientes, atuando como “capacitores de fertilizante”. *L. minor* tem potencial para ser utilizada como fonte de energia e representa uma alternativa sustentável para remoção de metais pesados do solo e do ar. Estudos sobre a aplicação de *L. minor* ainda apresentam áreas pouco exploradas, como alimentação para humanos e animais, pois o potencial proteico da espécie é um fator de interesse.

Palavras-chave: lentilha-d'água, fonte de proteína, produção de biomassa.



ABSTRACT

Lemna minor, commonly known as duckweed, is a species of aquatic macrophyte found in freshwater or low-salinity water bodies, typically protected from strong winds and currents, and generally forming dense populations that float on the water's surface. This review examines the existing knowledge on the use of duckweed across various scientific fields, highlighting its key advances and applications, while also identifying gaps and research areas that remain underexplored in relation to the species. Between 1972 and 2024, 341 publications obtained from Web of Science and Scopus databases were exported and analyzed using the tool Bibliometrix for definition and critical analysis of main authors, journals and countries. Articles involving *L. minor* are published in seven fields of knowledge: toxicity, bioremediation, growth factors, genetics, energy production, agriculture and animal supplementation. The three most cited articles in each area were recorded. Reviewed data suggest that the technology for growing aquatic plants is simple and cheap. Duckweed can absorb, decompose and reabsorb nutrients, acting as "fertilizer capacitors". *L. minor* has the potential to be used as a source of energy, and represents a sustainable alternative for removing heavy metals from soil and air. Studies on the application of *L. minor* still present little-explored areas, such as food for humans and animals, as the protein potential of the species is a factor of interest.

Keywords: duckweed, protein source, biomass production.

INTRODUCTION

Duckweeds are small, floating macrophytes distributed in various aquatic ecosystems around the world, primarily on the surface of slow-flowing waters (LANDOLT, 1986; ACOSTA et al., 2021). These monocots have undergone different taxonomic updates (APG IV, 2016) and are difficult to classify due to the morphological similarity and low genetic diversity between species, however, they are catalogued within the *Araceae* family, more precisely in the *Lemnoideae* subfamily (APG IV, 2016). The *Lemnoideae* have 38 species from 5 different genera (*Wolffia*, *Wolffiella*, *Spirodela*, *Lemna*, *Landoltia*) (CUSIMANO et al. 2011; APG IV, 2016). And, despite

their small size, water lentils (figure 1) exhibit a high growth rate under favorable conditions, primarily due to their predominantly asexual mode of reproduction (LANDOLT, 1986; IQBAL, 1999; IQBAL et al., 2019). This group of angiosperms has one of the highest propagation rates among plants, allowing duckweeds to double their weight in a few days, which implies a significant production of biomass in a short time (IQBAL, 1999; LANDOLT, 1987).

Furthermore, duckweed exhibits high tolerance to adverse environmental conditions, such as wastewater and brackish water (LENG et al., 1995), and contributes to the bioremediation of these systems (SKILLICORN et al., 1993).



Furthermore, they are also strong indicators of phytotoxicity, and their biomass is highly versatile, comprising a high percentage of proteins and producing large amounts of starch under stress conditions, which contributes to their use in numerous applications. In underdeveloped countries, duckweeds have significant aquaculture applications (LES et al., 2002), due to increased river eutrophication. They are highly productive and contain large amounts of amino acids, so they feed poultry, pigs and cows (HUQUE et al., 1996).



Figure 1. Numerous fronds of *Lemna minor*. Scale bar = 2 mm. (Photo by Frank Ensinger (ENSINGER, 2025). AI-generated scale bar (OPENAI, 2025)).

Figura 1. Numerosas frondes de *Lemna minor*. Escala bar = 2 mm. (Foto de Frank Ensinger (ENSINGER, 2025). Barra de escala gerada por AI (OPENAI, 2025)).

The concept of the circular economy is a

currently relevant topic with potential expansion. Considering the various applications of *L. minor*, this macrophyte has significant potential for applicability in the bioeconomy, particularly in multitrophic integrated aquaculture systems, where aquatic plants are introduced to mitigate the environmental impact of waste generated in aquaponics (KNOWLER et al., 2020).

Following the same theoretical line, these macrophytes can also be introduced into constructed Wetlands, which are low-cost effluent treatment systems designed to use plants to remove nutrients and are often associated with the site's landscaping (ABRAHAM, 2015). Furthermore, its biomass can be implemented as feed or used to produce other bioproducts.

OBJECTIVES

Because of the above, the objective of this work was to map, through a scientometric review, the scientific production of the use of duckweed in the most varied areas of knowledge, as well as identify the active researchers and the main journals in which it is distributed its scientific production.



MATERIAL AND METHODS

The literature search was conducted in two databases, Web of Science (WoS) and Scopus, during March 1972 and March 2024, as shown in figure 2. The data were filtered using the term “*Lemna minor* and application” in the topic item, which includes the title, summary, keywords, and keywords plus. No year filter was used to ensure that all studies presented in the database were included.

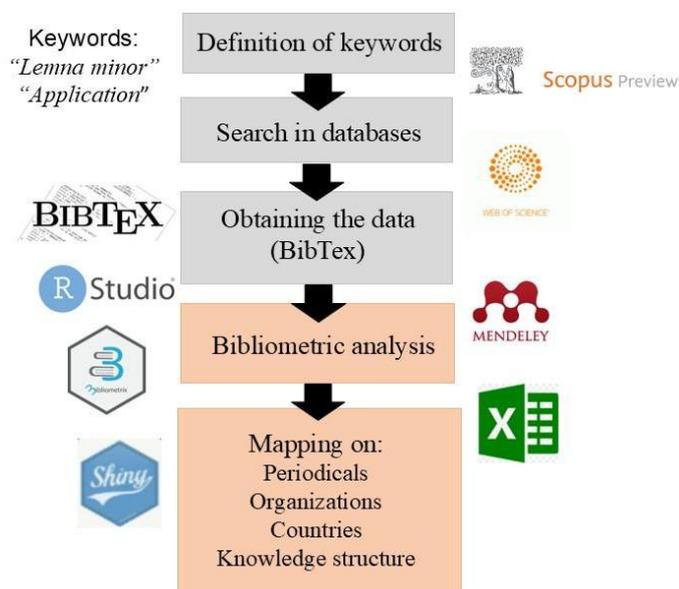


Figure 2. Generic flowchart of the methodology applied in this research.

Figura 2. Fluxograma genérico da metodologia aplicada nesta pesquisa.

Study selection was done based on specific inclusion criteria. The inclusion criteria include 1) primary research studies published in scientific journals in the English and Portuguese languages; 2)

the cultivar types should be only *Lemna minor*. Two researchers formulated a comprehensive search strategy to conduct the literature search. Duplicates were independently removed using R software (version 4.2.1), and abstracts and full texts were reviewed to exclude ineligible studies. Finally, the identified studies were retrieved and aggregated for review.

The data presented in this study were extracted directly from the Web of Science and Scopus databases, and after converting and uploading bibliographic data in R software (R version 4.2.1). Two researchers independently extracted data from the selected articles. Differing opinions were resolved through discussion. Descriptive analysis and further research structure analysis were performed in Bibliometrix and its Shiny platform.

RESULTS AND DISCUSSION

Study of publications and citations: year and field of publication, organizations and cooperation among countries

Based on the keywords used, “*Lemna minor* and application”, 401 scientific articles were found between 1972 and 2024. Of this total, 60 articles were removed because they did not meet the inclusion criteria, leaving 341 articles for analysis.



These were published in 191 journals with a total of 1285 authors. The first article, published in 1972 by Frick, Mohr (1972), evaluated the growth responses of green and etiolated *L. minor* when cultivated in the dark. Interest in *L. minor* has grown over the last five years, and the total number of articles published during this period accounts for 45% of all articles. Figure 3 illustrates the growth trend in the number of articles published during the analyzed period, alongside a significant decrease in the number of citations each year.

Articles involving *L. minor* are published in 7 fields of knowledge, with the highest number of publications having at least 16 records in the database. The field of toxicity accounts for 83 publication records, making it the largest field of study for *L. minor*. It is clearly seen that the fields of toxicity, bioremediation, and growth factors have led the research on this plant in terms of the number of articles published. The fields of large-scale cultivation and animal supplementation have 19 and 16 records, making them the seventh and eighth fields of study with regard to the number of articles published.

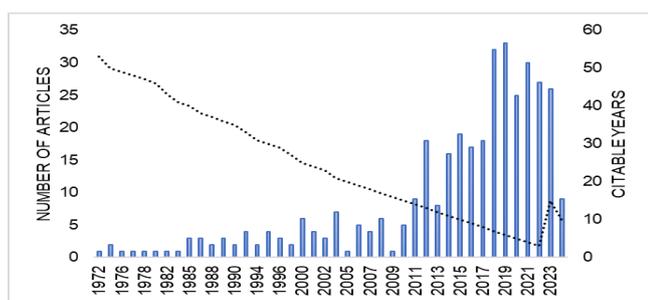


Figure 3 - Publication trends per year related to *Lemna minor* (Research done in the Web of Science® (WOS) and Scopus database during March 1972 and March 2024 using the term *Lemna minor* and applications in all topics).

Figura 3 - Tendências de publicação por ano relacionadas com *Lemna minor* (Pesquisa realizada no banco de dados Web of Science® (WOS) e Scopus durante março de 1972 e março de 2024 usando o termo *Lemna minor* e aplicações em todos os tópicos)

Among the organizations that represent the authors and co-authors of the papers, 523 institutions have published research related to *L. minor*, of which 12 are based in Brazil. University of São Paulo (table 1) stands out with 10 records. Two Brazilian institutions have published at least three articles each involving *Lemna minor*, whereas another nine institutions have published at least one paper. China and the United States are the countries that publish the most on the topic. This can be explained because China and the USA are the countries with the highest percentage of greenhouse gas emissions, reaching 6.2 billion tons of CO₂ (EPA, 2025a). Pollution causes problems for both environmental and public health; therefore, researchers are seeking alternatives that are environmentally suitable for water and soil treatment.

Furthermore, in China, duckweed (*L. minor* L.) is a common plant in rice fields, absorbing nutrients, heavy metals and agrochemical residues



from irrigation water, thus playing a fundamental role in the sustainability of the ecosystem. International cooperation between institutions exists, involving universities such as the University of Zagreb, the Chinese Academy of Sciences, Rutgers University, the University of São Paulo, the University of Toulouse, and Osaka University.

Table 1 - Publication areas, organizations, and countries that have published the most

Ranking	Name	Number	Percentage (%)
Publication area			
1	Toxicity	83	24.34
2	Bioremediation	65	19.06
3	Growth factors	63	18.47
4	Genetics	35	10.26
5	Production of energy	45	13.20
6	Agriculture	34	9.97
7	Animal Supplementatio n	16	4.70

Organizations

1	University College Cork	18	5.28
2	Ghent University	18	5.28

3	North Carolina State University	17	4.98
4	University of Aveiro	16	4.69
5	Osaka University	15	4.40
6	Chengdu Institute of Biology	10	2.93
7	Ege University	10	2.93
8	Rutgers University	10	2.93
9	University of São Paulo	10	2.93

Countries

1	China	146	42.81
2	United States	131	38.42
3	India	58	17.00
4	Germany	52	15.25
5	Japan	47	13.78
6	Brazil	39	11.44
7	Belgium	36	10.56
8	Poland	36	10.56
9	Czech Republic	35	10.26

* (%): percentage of 341 publications.

Articles, periodicals and author keywords analysis

Generally, a quotation analysis is used to identify the most frequently cited journals and



articles (table 2). The results reveal that Bioresource Technology, Aquatic Toxicology and Aquatic Botany are the most cited journals, which are 963, 516 and 417 times, respectively. It is also observed that the 14 most quoted journals represent 4177 (53%) of the 7916 total citations and that more than 89% of these studies have an impact factor higher than 4 (table 2).

Table 2 - Ranking of the most cited journals and documents

Journal	ND	NC	Impact Factor*
Bioresource Technology	17	963	11.4
Aquatic Toxicology	12	516	4.5
Aquatic Botany	9	417	1.8
Environmental Science and Pollution Research	15	233	5.8
Chemosphere	11	222	8.8
Ecotoxicology and Environmental Safety	9	222	6.8
Environmental Toxicology and Chemistry	8	398	4.1
Science of the Total	7	179	9.8

Environment

Biotechnology for Biofuels	5	286	6.3
Water Research	5	160	12.8
Ecological Engineering	4	147	3.8
Journal of Hazardous Materials	4	181	13.6
Biomass & Bioenergy	3	135	6.0
Environmental Pollution	5	118	8.9

Author	NC	Journal
Cox <i>et al.</i> (2006)	323	Nature Biotechnology
Pomati <i>et al.</i> (2004)	192	Aquatic Toxicology
Cedergreen <i>et al.</i> (2009)	169	Environmental Toxicology and Chemistry
Nardi <i>et al.</i> (2004)	149	European Journal of Agronomy
Alvarado <i>et al.</i> (2008)	144	Bioresource Technology
Xu <i>et al.</i> (2011)	136	Biosystems Engineering



Zuverna-Mena <i>et al.</i> (2015)	115	Environmental Science: Process & Impacts
Ge <i>et al.</i> (2012)	103	Bioresource Technology

ND: number of documents; NC: number of citations

* Impact factor in the year 2022

Main studies and application area of *Lemna minor*

Among the 341 publications, the three most relevant articles within each area of knowledge were selected based on the number of citations (table 3).

Phytoremediation

Environmental pollution by heavy metals has become a global concern in recent decades, with high concentrations exceeding tolerable levels in both water and soil. Various techniques can be used for soil and water decontamination, including phytoremediation, which uses plants to degrade, extract, contain or immobilize soil and water contaminants. The low investment and operating costs, in situ application, and minimal degradation and destabilization of the area to be decontaminated are advantages of

this technique. Although the limitations of this technique involve factors such as climate, soil, concentration and depth of the contaminant, season and time spent in the decontamination process, it has been tested for removing inorganic compounds such as nitrates and cyanides, organic compounds such as hydrocarbons derived from petroleum and heavy metals.

Arsenic (As) is one of the most toxic elements that can be found in water at a maximum concentration of 0.05 mg/L (EPA, 2025b). Several methodologies have been tested for arsenic removal to find those that are low-cost and easy to implement. Alvarado *et al.* (2008) showed that there was no significant difference in the bioaccumulation capacity of As by *L. minor* and *Eichhornia crassipes* when they were maintained in a solution with a concentration of 0.15 mg As/L for 21 days, indicating that both species represent a reliable alternative for bioremediation of arsenic in water.

In another study, Alp *et al.* (2023) evaluated the protective effects of Scandium (Sc), at concentrations of 50 µM and 200 µM, on the growth and changes in the metabolism of *Lemna minor* when exposed to different concentrations of chromium (Cr) - 100 µM, 200 µM and 500 µM.



Table 3 - Most relevant studies on the application of *Lemna minor* within each area of knowledge

Area	Title	Citation number	Reference
Toxicity			
	Effects of erythromycin tetracycline and ibuprofen on the growth of <i>Synechocystis</i> sp and <i>Lemna minor</i>	192	POMATI <i>et al.</i> (2004)
	Anatoxina elicits an increase in peroxidase and glutathione transferase activity in aquatic plants	77	MITROVIC <i>et al.</i> (2004)
	Possible ecological risk of two pharmaceuticals diclofenac and paracetamol demonstrated on a model plant <i>Lemna minor</i>	76	KUMMEROVÁ <i>et al.</i> (2016)
Bioremediation			
	Arsenic removal from waters by bioremediation with the aquatic plants water hyacinth <i>Eichhornia crassipes</i> and lesser duckweed <i>Lemna minor</i>	144	ALVARADO <i>et al.</i> (2008)
	Biomass production and npk retention in macrophytes from wetlands of the Tingitan Peninsula	79	ENNABILI <i>et al.</i> (1998)
	Nutrient removal from swine lagoon liquid by <i>Lemna minor</i>	72	CHENG <i>et al.</i> (2002)
Growth factors			
	In vitro selection of duckweed geographical isolates for potential use in swine lagoon effluent renovation	84	BERGMANN <i>et al.</i> (2000)
	The first draft genome of the aquatic model plant <i>Lemna minor</i> opens the route for future stress physiology	74	VAN HOECK <i>et al.</i> (2015)



research and biotechnological applications

New method for determining effluent toxicity using duckweed <i>Lemna minor</i>	70	TARALDSEN, NORBERG-KING, (1990)
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Genetics

Glycan optimization of a human monoclonal antibody in the aquatic plant <i>Lemna minor</i>	323	COX <i>et al.</i> (2006)
Molecular farming of pharmaceutical proteins using plant suspension cell and tissue cultures	82	SCHILLBERG <i>et al.</i> (2013)
Genetic transformation of duckweed <i>Lemna gibba</i> and <i>Lemna minor</i>	54	YAMAMOTO <i>et al.</i> (2001)

Production of energy

Growing <i>Lemna minor</i> in agricultural wastewater and converting the duckweed biomass to ethanol	103	GE <i>et al.</i> (2012)
Pyrolysis of fastgrowing aquatic biomass <i>Lemna minor</i> duckweed characterization of pyrolysis products	96	MURADOV <i>et al.</i> (2010)
Production and characterization of <i>Lemna minor</i> biochar and its catalytic application for biogas reforming	88	MURADOV <i>et al.</i> (2012)

Agriculture

Evaluation of heat shock protein 70 as a biomarker of environmental stress in fucus serratus and <i>Lemna minor</i>	79	IRELAND <i>et al.</i> (2004)
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Response of antioxidant defences to zn stress in three duckweed species	59	URUÇ PARLAK, YILMAZ (2012)
Genetic transformation of Indian isolate of <i>Lemna minor</i> mediated by agrobacterium tumefaciens and recovery of transgenic plants	34	CHHABRA et al. (2011)

Animal Supplementation

Duckweed as an aquatic crop evaluation of clones for aquaculture	63	PORATH et al. (1979)
Mass production of <i>Lemna minor</i> and its amino acid and fatty acid profiles	38	CHAKRABARTI et al. (2018)
The application of multielemental analysis in the elaboration of technology of mineral feed additives based on <i>Lemna minor</i> biomass	33	CHOJNACKA (2006)

The authors concluded that the higher Sc concentration improved the photosynthetic efficiency and chlorophyll fluorescence of *Lemna minor* at concentrations of up to 200 µM chromium, mitigating the damage caused by Cr toxicity.

Toxicity

While contamination by heavy metals is a concern, on the other hand, contamination of aquatic ecosystems with active pharmaceutical substances via sewage discharge, inadequate

disposal or industrial waste has also been recognized as an emerging environmental problem. These emerging substances can affect the aquatic ecosystem and potentially disrupt important natural ecosystem processes, such as the decomposition of organic matter (BUNDSCHUH, SCHULZ, 2011)

One of the alternatives used in the evaluation and control of effluents, aiming at regulatory aspects or national legislation, is ecotoxicological tests, which are often conducted using *L. minor* as a bioindicator of



toxicity (BUNDSCHUH, 2014). Ecotoxicological tests using aquatic plants have been used to evaluate the toxicity of organic and inorganic contaminants, such as sediments, solid waste and complex matrices, such as domestic and industrial wastewater (APPENROTH et al., 2013).

A study carried out by Pomati et al. (2004) tested the effect of the antibiotics erythromycin, tetracycline and ibuprofen on the growth of *Lemna minor*. The authors showed that erythromycin and tetracycline were more effective in promoting the synthesis of the stress hormone abscisic acid compared to ibuprofen. In another study, Kummerová et al. (2016) reported that indicators of phytotoxicity stress in duckweed were changes in biochemical processes, linked to the activation of defense mechanisms against oxidative stress when exposed to the drugs diclofenac and paracetamol. Landolt et al. (1987) demonstrated that aquatic macrophytes changed in terms of growth and reproduction when exposed to herbicides.

Growth factors

Currently, the study of macrophyte growth has been considered very important, since these plants play a fundamental role in aquatic ecosystems, whether as producers of

oxygen gas or as habitats for various organisms. Another reason for studying macrophytes is their potential for use in wastewater treatment (OZENGİN; ELMACI, 2007) and, in this way, the importance of work that models the growth of this type of plant stands out.

Another aspect highlighted by Palafox et al. (2005) is the high adsorption capacity of *L. minor*, which, as it is a floating macrophyte, adsorbs considerable amounts of nutrients and/or heavy metals present in water and this causes its nutritional values to reach levels that allow its use in animal feed. domestic animals such as ducks (ARROYAVE, 2004).

Khellaf, Zerdaoui (2009), in their study on the growth response of *L. minor* under conditions of high concentration of heavy metals, describe its adsorptive capacity as hyperaccumulator potential, which is also seen in the study by Jain et al. (1988), specialized in the accumulation of nickel-Ni, copper-Cu and manganese-Mn.

Several authors have demonstrated the influence of environmental factors on the growth of *Lemna* spp., particularly temperature, illuminance and pH for optimal growth of the macrophyte *L. minor* (HILLMAN; CULLEY, 1978; ZIEGLER et al., 2015). The ideal temperature for the growth of *L. minor* is in the range of 22-26°C,



the pH in the range 5-9, and the light intensity range between 6500-10000 Lux (CHENG; STOMP, 2009; OECD, 2006).

Genetics

Due to the advancement of biotechnology, the use of plants in medicine is on the rise. In the case of plants, the production of recombinant proteins in genetically modified plant systems, where the introduced gene encodes the desired product, is known as Molecular Farming (OAKES et al., 1991).

Heterologous expression of proteins in plants offers several advantages. One of the main advantages is its safety concerning other expression systems, as there is no danger of contamination with human or animal pathogens, oncogenic DNA sequences or endotoxins that could put human health at risk. (DANIELL et al., 2001; DIRISALA et al., 2017; MOUSTAFA et al., 2015; SCHILLBERG et al., 2002; WILSON ; ROBERTS, 2012; XU et al., 2012).

There are also economic advantages: it is cheaper to produce recombinant proteins in plants compared to animal cell systems (HORN et al., 2004; TWYMAN et al., 2003). *L. minor* has been used for the production of recombinant proteins. In this sense, Cox et al. (2006) expressed human monoclonal antibodies

(mAbs) in the aquatic plant *Lemna minor* aiming to evaluate glycosylation against human CD30. The resulting mAbs contained a single major N-glycan, without specific N-glycans, and exhibited better antibody-dependent cell-mediated cytotoxicity and improved cellular receptor binding activities compared to mAbs expressed in cultured Chinese hamster ovary (CHO) cells.

Production of energy

However, the application potential of duckweed lies in its ability to remove heavy metals and contaminants in bioremediation processes. The production of ethanol and biomethane from duckweed is a well-documented factor in the literature. This is due to the high cellulose content of these macrophytes and thanks to the plant's rapid starch accumulation capacity, triggered by nutrient starvation. Furthermore, its biomass has few traces of hemicellulose and undetectable lignin, indicating that, even without thermal pretreatment, it is possible to enzymatically obtain up to 96% of the glucose from a duckweed inoculum, enabling high-efficiency ethanol production. Ge et al. (2012) cultivated genera of *Lemna*, *Spirodela*, *Wolffia* and *Wolffiella* in diluted swine lagoon effluent,



and then used them as raw material for the production of bioethanol, obtaining a conversion of 0.085 g/g of biomass.

In this sense, concerning the production of biomethane from duckweed, Calicioglu, Brennan (2018) compared two different processes. In the first study, the authors carried out direct anaerobic digestion of the dry biomass of duckweed, while in the comparative study, the authors carried out prior fermentation of the biomass, for subsequent anaerobic digestion. In this way, it was possible to conclude that, with the prior fermentation of the biomass, the biomethane yield was higher (51.2%) compared to the digestion of raw biomass, resulting in an increase in energy gain of 70.4%.

What makes this subfamily of macrophytes even more attractive beyond bioenergy production is its high potential to transform polluting wastewater into a biofuel production system, as duckweed preferentially removes nitrogen in the form of ammonia (MONSELISE, KOST, 1993). The subsequent application of biomass from remediation to the production of fuels and petrochemicals offers an environmentally friendly and cost-effective solution to water pollution problems and the

production of value-added products (MURADOV et al., 2014).

Agriculture

Ofoedu et al. (2025) highlight the potential of growing lentils in floating hydroponics systems for the production of biomass for food, animal feed, biofuels and other industrial uses. To implement this technique, Cui, Cheng (2014) recommend careful plant selection and washing with clean water before planting. Furthermore, Ullah et al. (2023) emphasize the importance of maintaining water pH within the ideal range for plant cultivation. According to these authors, to ensure an ideal pH for duckweed cultivation, values should range between 6.5 and 7.5. It is recommended that the water be adjusted accordingly. Nutrition and maintenance of the system are crucial to the success of duckweed cultivation. The aforementioned authors suggest that the ideal pH probably varies depending on the species of lentil grown, as well as other environmental conditions.

Chen et al. (2022) recommend the appropriate use of suitable fertilizers and constant monitoring of water quality, including pH, conductivity and temperature, and adjusting as necessary. Removing debris and



residue from plants and the system is necessary to ensure that plants receive clean, debris-free water, as suggested by Paolacci et al. (2021). Finally, it is essential to monitor water quality regularly and take immediate corrective measures in the event of imbalances, as highlighted by Cui and Cheng (2014). It's essential to remember that duckweed cultivation is highly sensitive to changes in water quality; therefore, it is crucial to monitor water quality regularly and take corrective measures promptly in the event of imbalances.

Animal Supplementation

Considered an important source of carbohydrates, proteins, and dietary fiber, duckweed plays an important role in controlling and preventing metabolic diseases. Graeff et al. (2007) obtained 45% proteins, 5.34% lipids, and 6.3% soluble carbohydrates, totaling a fraction of 86.5% organic material contained in the biomass when evaluating the proximate composition of *Lemna minor*. Among the applications of biomass from this species, the same authors argue that *Lemna flour* can replace soy flour in the formulation of feed for breeding *Cyprinus carpio*, however, the maximum percentage to be used is 6%. In animal feed, two key components that must be

considered are the protein composition and the fibrous fraction.

CONCLUSION

Duckweed has been used to mitigate environmental pollution and valorize wastewater by removing excess nitrogen and phosphate. It is a species that represents a potential alternative for removing heavy metals, and it is an effective and viable process in decontaminating terrestrial and aquatic environments.

On the other hand, duckweed can be a potential alternative to plant-based proteins through more sustainable production, which minimizes greenhouse gas emissions and, consequently, contributes to reducing global warming and mitigating climate change. Due to its remarkable biomass yield, resilience to various abiotic factors, compact size, and rich protein content—and especially its ability to be cultivated in recirculating water systems or vertical farming setups—it stands out as an excellent option for inclusion in the human diet.

Widely consumed across Asia and already approved by the FDA, *L. minor* still requires extensive research to evaluate its acceptance as a food source and its nutritional potential, as well as to assess how different



production methods may influence its final composition. While it has already demonstrated significant value in animal feed, its gradual incorporation into the human diet is recommended. Moreover, its application could strongly support several Sustainable Development Goals (SDGs): goal 2 (Zero Hunger and Sustainable Agriculture) by providing nourishment for humans in addition to benefiting livestock; goal 12 (Responsible Consumption and Production) through its reduced soil impact during cultivation; and goal 13 (Climate Action) by contributing to global efforts against climate change.

In the coming years, existing food supply chains will face increasing pressure, heightening the urgency to identify viable alternatives to the vegetables currently consumed. Therefore, it is plausible that within the next five years, *L. minor* could appear on supermarket shelves—either sold in bulk or incorporated into food products—provided that ongoing research and safety validations confirm its suitability. Future investigations should focus on optimizing its cultivation and identifying the environmental conditions that best support its growth. There is also a clear need for studies aimed at increasing protein production through the manipulation of nutritional sources and improving palatability

aspects. Therefore, increasing public exposure to *L. minor* and conducting consumer acceptance studies are supported not only by the numerous benefits this plant can offer to consumers but, perhaps more importantly, by its positive impact on the environment.

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