



## Common duckweed (*Lemna minor*): food and environmental potential. Review



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### Abstract:

Common duckweeds are flowering plants of the family Araceae, comprising the smallest angiosperms of the plant kingdom, a species of aquatic algae of universal distribution, found on the surface of freshwater bodies, mainly in puddles, swamps, lakes, and calm rivers. Recently, different research has been carried out on its potential and usefulness. Due to its nutritional composition, protein contribution, high fiber content and low fat and carbohydrate content, it would be an adequate input to generate products of high nutritional value, characteristics that make it interesting compared to other species. It is used as a complement to commercial diets in a wide variety of animals such as birds, ruminants, non-ruminants, crustaceans, and fish, reducing feed costs by up to 50 %. Likewise, used in remediation processes of a wide range of chemical contaminants with a high elimination rate, they can absorb some dissolved substances and provide oxygen through photosynthesis. It has been indicated that they are low cost of construction, maintenance, easy to operate, have a wide tolerance to growing conditions, are generally easy to harvest, and do not compete with farmland. In the environmental field, it is important to find alternative and innovative raw materials, even without the need to use growth media or fertilizers, however, their acceptance as a food source needs extensive research regarding their nutritional value, large-scale yield, economic market supply and analysis of antinutritive components for human food.

**Keywords:** Common duckweed, *Lemna minor*, Nutritional profile, Environmental remediation, Human and animal food.

Received: 30/11/2021

Accepted: 27/07/2023

## Introduction

In recent decades, the rapid growth of the world's population and the climate crisis have become a serious problem that threatens the food and feed supply, generating dietary patterns deficient in proteins and vitamins, the development of malnutrition due to excessive consumption of simple sugars and stigmatization of nutrients<sup>(1)</sup>. In this sense, common duckweeds have taken center stage in recent research in the search for new foods that provide healthy alternatives, pharmaceutical products that are sustainable and profitable on a large scale of production.

These small aquatic plants comprise a group that float on the surface of bodies of water with little movement, with a great capacity for reproduction and accelerated growth. Traditionally, they have been used as remediation agents for water body pollution due to their ability to absorb minerals, salts, nitrogenous substances, and heavy metals in water bodies<sup>(2)</sup>.

From an ecological point of view, it can be seen that, given its interactions with other species, it can be considered as a keystone species in its habitat, although it has a small size, due to its rapid growth, high tolerance to pollution and capacity to absorb nitrogen and phosphorus, *Lemna minor* has previously been used for wastewater treatment<sup>(3,4)</sup>.

In Asian countries and recently in Western countries, they are being included in plant mixtures for the raising of farm animals and fish cultures, showing favorable results in the development and growth of these animals, reducing feeding costs<sup>(2)</sup>.

Common duckweeds are known to contain essential nutrients such as protein, carbohydrates, and fats. They also contain a variety of secondary metabolites that are beneficial to humans. Therefore, consideration of common duckweed cultivation methods is vital for their best utilization in various industrial applications. A number of reports have been generated on common duckweed utilization, metabolites, and cultivation; these should be reviewed and summarized as fundamental information to improve the application of common

duckweeds<sup>(5,6)</sup>. It is important to note that if they are used as pollution remediation agents, their use in human and animal food should be evaluated.

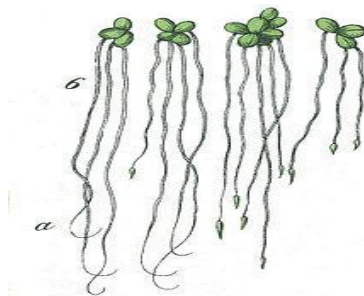
This paper aims to provide a global overview of common duckweeds, especially the species *Lemna minor*, through a bibliographic review from taxonomic description to their use as an alternative for inclusion in animal and human diet, considering their nutritional composition and current lifestyle patterns. In addition, environmental impact as biomarkers, environmental remediators, agricultural amendments in crops, biofuel sources and pathogenesis models is studied.

### Common duckweed (*Lemna minor*)

Common duckweed (*Lemna minor*) is the world's fastest-growing, free-floating aquatic angiosperm plant that grows in immobile waters, usually in freshwater or wetlands in most parts of the world and is characterized by its small size and great reproductive capacity, which allows it to occupy large aquatic spaces in a truly short time<sup>(7,8)</sup>. They are generally described as aquatic or floating grasses of quite simple structure, lacking stem, or leaves, occasionally with small thread-like roots on their underside. It is an aquatic plant that can often be seen floating or just below the surface or moving very slowly<sup>(9)</sup>.

*Lemna minor* has a thalloid-shaped vegetative body, characteristic of some plants in which it is not possible to differentiate the leaves from the stems, small in size with a flat structure, green coloration in its leaves and a single thin white root. According to the description of some authors, this characteristic is associated with a modified leaf that fulfills the functions of the stem, leaf, and axis to support flowers, as shown in Figure 1<sup>(10,11)</sup>.

**Figure 1:** Illustration of the vegetative body and roots of common duckweed (*Lemna minor*)



Source: Landolt, E<sup>(11)</sup>.

On the other hand, roots, generally related to the nutrient uptake aspect of the plant, seem to have a slightly different function in these species. Some researchers have reported that the consumption of nutrients via roots is little or non-existent, functioning as a stabilizing organ in the body of water; however, the common duckweed, *Lemna minor*, has been shown to acquire significant amounts of inorganic nitrogen through the root. The plant grows at different temperatures varying between 5 and 30 °C, growing optimally between 15 and 18 °C. It adjusts favorably to any lighting conditions. It grows rapidly in calm, nutrient-rich locations with high levels of nitrogen and phosphates. Iron often limits the proper development of this species. It is also tolerant to a wide pH range, between 4.5 and 7<sup>(12,13)</sup>.

### **Cultivation of common duckweed (*Lemna minor*)**

Common duckweed crops can be produced quite easily and inexpensively, even without the need to use growth media or fertilizers, as they are characterized by a high relative growth rate (RGR). This means that they are able to produce large amounts of biomass in a short time and in relatively small ponds, filled with a few centimeters of natural water (30 to 50 cm deep). The control and monitoring of the aquatic medium in which the plants grow is particularly important. The productivity of common duckweed increases more if the optimal ecological conditions for growth are respected, however, they are generally broad. These, although varying slightly from species to species, generally consist of moderately warm, sunny, nutrient-rich waters, as documented in ecological studies on some common duckweed species of the genus *Lemna*.

In recent decades, it has become common to grow them outdoors, but it can be difficult to optimize and control operationally. However, common duckweeds also represent a suitable crop for indoor farming, with most species, due to their flat structure particularly suitable for cultivation in multi-level (stacked) systems that use indoor floor space efficiently. Indoor cultivation also expands the scope of crop managing and allows for pest-free conditions and even sterile conditions. However, the technical and operational parameters required for large-scale effective interior have received little attention in the literature<sup>(14)</sup>.

It is important to note that sporadic common duckweed growth causes serious damage to aquatic resources, with several economic implications. The dense and extensive blanket created by the plant in the block of surface water and water channels makes activities such as water flow, sailing, canoeing, swimming, and fishing impossible. It also affects irrigation, floods canals, can clog hydroelectric turbines and disturbs rice fields. A dense layer of common duckweeds shuts out and inhibits competing aquatic plants, including algae that

require sunlight. For this reason, it is important to have integrated control or strategies that allow their exploitation.

According to various objectives and targets, optimal cultivation of common duckweeds will be necessary from an economic and industrial point of view. Various cultivation methods using various types of bioreactors and conditions for their use as food resources, pharmaceuticals, phytoremediators, and biofuels must be employed. Aquaponics combining aquaculture and hydroponics could be a sustainable production system for plants<sup>(15)</sup>. Currently, the technology enables the mass production of good quality by controlling environmental conditions, such as irrigation irradiation, atmospheric pressure, wind, speed, temperature, and humidity.

## **Nutritional composition**

In recent decades, several scientific studies have highlighted the nutritional value of common duckweeds, which, due to their supply, could improve the quality of food in the future. However, according to some studies, the metabolism of the plant and, therefore, its nutritional composition depends a lot on the nutrients found on the surface of the body of water in which it is found. These extremely important factors capable of influencing the nutritional composition of the plant are reflected in the different results obtained in each study<sup>(16)</sup>.

### **Proteins**

The high-quality protein content reaches 20 to 35 % in dry matter, when grown under optimal conditions, higher than the protein present in cereals<sup>(6)</sup>. This means that common duckweed biomass can be considered as an ingredient for animal or human food and can contribute to improving food security through the development of sustainable methods of producing food with high nutritional value<sup>(17)</sup>. It has been documented that the protein production of common duckweeds per harvested area was higher than that of soybeans, rice, and corn; therefore, it could solve the problem of the scarcity of arable land to produce food<sup>(5)</sup>.

The amino acid profile of common duckweeds stands out from some plant-based protein sources currently known in the human diet, an aspect that some authors have come to relate to an amino acid profile more similar to animal protein<sup>(18,19)</sup>. Recent studies analyzing the nutritional composition of several common duckweed crops showed, unlike previous analyses, a content of amino acids, such as isoleucine, leucine, cysteine, methionine,

threonine, and valine, similar to the recommendations for consumption for the population (Table 1); it can also be noted that the amounts were not lower than those recommended by the WHO, 2007<sup>(20,21)</sup>. Jahreis *et al*<sup>(20)</sup> found that the amino acid composition of common duckweeds is comparable to that of legume meals, such as chickpeas, lupins, or peas. Clinical nutrition studies have shown that the essential amino acids and vitamin B<sub>12</sub> content of common duckweeds are comparable to peas and cheese<sup>(5)</sup>.

In addition, their source of proteins, which could replace soybean meal, is expected to be used as a substitute to reduce environmental pollution created by the expansion of soybean cultivation<sup>(21)</sup>. Consumption of plant protein instead of animal protein could reduce energy use and greenhouse gases and alleviate the negative aspects of feed production<sup>(5)</sup>.

**Table 1:** Amino acid content of common duckweed (*Lemna minor*)

Amino acids		G / 100 g protein
Cysteine	CYS	0.9
Methionine	MET	1.6
Asparagine	ASP	8.2
Threonine	THR	4.0
Serine	SER	4.1
Glutamine	GLU	9.8
Glycine	GLY	4.6
Alanine	ALA	5.1
Valine	VAL	4.6
Isoleucine	ILEU	3.7
Leucine	LEU	7.3
Tyrosine	TYR	3.1
Phenylalanine	PHE	4.4
Lysine	LYS	5.0
Histidine	HIS	1.5
Arginine	ARG	4.8
Proline	PRO	3.8

Source: Appenroth, *et al*<sup>(7)</sup>.

## Fats

Fats play an important role in the human diet; despite being stigmatized as nutrients harmful to health, in the last decade some studies have shown the great impact they have by contributing as protective factors against degenerative diseases such as Alzheimer's,

reducing the risk of cardiovascular accidents and even, mortality. Authors report a content of 4 to 6 % fat content per dry weight<sup>(6)</sup>.

An approximate content of 30 % saturated fatty acids, specifically high levels of palmitic acid, is highlighted. Recently, in terms of fatty acid contribution by common duckweeds, it has been shown that it adapts very well to the requirements of the human population, with a low fat intake and a good ratio of polyunsaturated to monounsaturated fatty acids, generally close to or more than half of the total fatty acid content, ranging from 55 to 63 %<sup>(22)</sup>. It is also important to highlight the presence of n-3 class polyunsaturated fatty acids (alpha-linolenic, eicosapentaenoic, and docosahexapentaenoic acids), which are important in human metabolism and act as anti-inflammatories<sup>(23)</sup>. Other authors have described that 48 to 71 % of fats are polyunsaturated fatty acids and the ratio of omega-6 to omega-3 fatty acids is 0.5 or less<sup>(6)</sup>.

## **Carbohydrates and fiber**

Several studies with common duckweeds have concluded that starches or carbohydrates are fairly underrepresented in the analysis of the nutritional composition of these plants; in the best of cases, carbohydrates represent approximately 10 % of the total nutritional value of common duckweeds<sup>(24)</sup>.

Some authors have shown that the growth environment, genetics of the species, nutrients of the medium, temperature range, time, and intensity of sunlight cause differences in the biochemical components (crude protein, ash, cellulose, water, fats, and minerals). It has been documented that the protein content of common duckweed depends primarily on the nutrient content in the water body, while the accumulation of minerals in common duckweed tissue depends primarily on the water conditions in the growing environment. During artificial cultivation, the starch, lipid, and protein content in common duckweeds can be controlled by changing factors affecting the common duckweed growing environment, such as pH value, temperature, medium structure, etc.<sup>(25)</sup>.

On the other hand, the fiber content, unlike carbohydrates, is considerably high; common duckweeds can contain up to 25 % of the total nutritional value in fiber<sup>(26)</sup>. This high fiber content represents an excellent option for inclusion in the human diet, which, together with a large contribution of protein and a small contribution of fats and carbohydrates, would be, according to several authors, completely beneficial in healthy lifestyles<sup>(27)</sup>.

## Minerals and trace elements

The nutritional composition in terms of minerals in common duckweeds is characterized by being plants rich in potassium and iron, and poor in sodium; in contrast, in terms of trace elements, the content of manganese, zinc, copper, among others, stands out (Table 2). On the other hand, the total ash content is moderately high, with ranges of up to 18 % in some studies, however, these values may vary according to the composition of the medium<sup>(6,26)</sup>.

**Table 2:** Contribution of trace elements from common duckweeds in mg per kg of total edible part

Trace elements		mg / kg
Magnesium	Mg	2850 ± 710
Iron	Fe	230 ± 90
Manganese	Mn	230 ± 98
Iodine	I	0.39 ± 0.19
Cadmium	Cd	0.076 ± 0.145

Source: Ziegler P, *et al*<sup>(26)</sup>.

## Vitamins

Regarding vitamins, there are few studies on common duckweeds that have focused on assessing the nutritional composition and presence of these micronutrients. The vitamins found in the highest amount in common duckweeds are carotenoids, precursors of vitamin A; the dominant carotenoid in this plant is lutein, followed by  $\beta$ -carotene. Other carotenoids are found in much lower amounts, such as  $\alpha$ -tocopherol and zeaxanthin<sup>(28,29)</sup> (Table 3).

**Table 3:** Carotenoid content in common duckweeds

Nutrients carotenoids		Contribution
Lutein	mg/100 g	40 – 80
$\beta$ -carotene	mg/100 g	10 – 30
$\alpha$ -tocopherol	mg/100 g	0.5 – 13
Zeaxanthin	mg/100 g	0.8 - 10

Source: Sree K, *et al*<sup>(28)</sup>.



## Human nutrition

In a study carried out by the Panel on Nutrition, Novel Foods, and Food Allergens (NDA) on the safety of the complete plant material of *Lemna minor* and *Lemna gibba* as a novel food in accordance with Regulation (EU) 2015/2283 in 2022<sup>(17)</sup> for consumption as a vegetable, toxicological, nutritional, microbiological analyses of powder from common duckweeds grown in greenhouses under controlled conditions were carried. Based on the proposed uses, expected intake and compositional data, the intake of heavy metals, microcystins and micronutrients, except manganese, it does not pose safety concerns for consumption as a novel food. However, the findings on neurotoxicity and the possible higher susceptibility of some subgroups of the general population, oral exposure to manganese beyond that normally present in foods and beverages could pose a risk of adverse health effects without evidence of any health benefit. On the other hand, the likelihood that the product may trigger allergic reactions in humans is similar to that of other leafy vegetables, and therefore the level of risk is considered low.

In this research, there were two human trials: a randomized crossover trial and a parallel controlled trial with healthy subjects. The commission's panel noted that the human studies provided were primarily designed to research putative beneficial effects and addressed only a limited number of safety-relevant evaluation criteria. The Panel considers that no adverse events related to consumption were reported, however, it is noted that no conclusions can be drawn from these studies about the safety of the product.

In some parts of Southeast Asia, such as Laos, Thailand and Myanmar, its consumption is normal in preparations such as salads, soups, curries or omelets as a source of vegetable protein, however, it has not been included as part of the diet in Western countries<sup>(16)</sup>.

Common duckweed has been shown to have an amino acid profile that favors the diet of aquatic and terrestrial animals, a contribution of vitamins and minerals that contribute to its palatability, a concentration of fats (4 to 7 %) and starches (4 to 10 %) adequate when compared to other plant-based foods such as dried legumes; in addition, knowing the poverty rates in some populations of the world, and the high need for nutritional supplementation in populations with limited access to healthy food, it could be of great relevance in human nutrition<sup>(16,30)</sup>.

In the case of Thailand, common duckweeds, in their variety of species, are marketed in vegetable markets and their acceptance in the population such as Khai Nam, Khai Pum, and Khai Phae (generally translated as “water eggs”) stands out in the preparation of traditional local dishes such as salads, curried vegetables, and omelets<sup>(31)</sup>.

Israeli studies seeking to compare the postprandial and nocturnal glycemic response by using dairy shakes from common duckweeds of the species *Wolffia globosa* observe in these plants a great opportunity in human nutrition, especially in population groups with difficulties in carbohydrate metabolism. According to these studies, this species of algae could serve as an emerging alternative plant protein source with potential beneficial postprandial glycemic effects, however, no scientific information has been found with the species *Lemna minor*<sup>(29)</sup>.

Considering the nutritional contribution of common duckweeds, especially their outstanding contribution of proteins, fats, beta-carotenes, minerals, and low carbohydrate contribution, in addition to the absence of antinutritional substances, common duckweeds (*Lemna minor*) could represent an excellent option for consumption as a supplement in the dietary pattern of needy communities throughout the world<sup>(32)</sup>. However, in cases of uncontrolled growing conditions, and particularly when fertilizers, pesticides and other organic contaminants are present in large quantities at cultivation sites or in cases of water pollution by algae or microbes, the high concentration of contaminants or toxins in those plants may pose a potential risk to human health that should be considered<sup>(17)</sup>. On the other hand, Appenroth *et al*<sup>(6)</sup> indicate that *Wolffiella hyalina* and *Wolffia microscopica* are suitable for human nutrition, even compared to other common duckweed species, regarding amino acid composition and fatty acid distribution.

## **Animal nutrition**

The high cost of feed for animal raising has led to the constant search for alternatives to improve animal production. At present, soybean meal is one of the most widely used alternative ingredients to replace fishmeal in animal feed due to its high protein content and relatively well-balanced amino acid profile, which can generally meet the requirements of many fish species. However, soybean meal is already in high demand in the human food chain, both directly and indirectly in feed for farmed terrestrial animals. This competition means that soybean meal is an expensive ingredient and this may limit its use as an ingredient to meet future fish feed demands. Therefore, there is a constant need to find other ingredients (insects, vegetables, algae, byproducts of aquatic organisms) to replace both fishmeal and its main substitute, soybean meal, in farmed fish feed. Ideally, such ingredients should be unconventional in order to avoid or minimize competition with other animal feed sectors<sup>(33)</sup>.

Among these alternatives, common duckweed represents a great opportunity given its accelerated growth and great ability to adapt to the environment in which it grows; this, without leaving aside the source of raw vegetable protein that it represents, its contributions

of minerals, xanthophylls and amino acids such as lysine, threonine, and valine<sup>(18,34)</sup>. Hence the great opportunity from an economic point of view that it can represent.

Under experimental conditions, the production rate can be close to 183 extrapolated metric tonnes/ha/year of dry matter, although yields are closer to 10-20 tonnes DM/ha/year under real conditions. Its use has mostly occurred in a wide variety of animals of social interest such as farmed birds, ruminants, non-ruminants, and farmed fish<sup>(35)</sup>. In which, through different inclusion models, it has been shown that it can be a good complement to the food diet of livestock and fish<sup>(36,37)</sup>.

Models implemented in small farms in the Asian continent focused on the recovery of nutrient flow from animal waste have used the resulting common duckweed biomass as a fresh feed for ducks, farmed fish and pigs; all this evidencing the contribution to the correct nutrition of these animals and reducing feed costs<sup>(7,38,39)</sup>.

Common duckweed has similar or superior characteristics to plant-based proteins, such as legumes, however, it is rich in some essential amino acids. In Asian and Latin American countries, there are reports of the use of common duckweed in the diet of farmed pigs, with an inclusion of up to 10 % of the total feed consumption, showing excellent results in their reproductive response<sup>(37)</sup>.

In Latin American countries such as Mexico and Venezuela, common duckweed is used to feed pregnant sows and piglets, replacing 80 % of protein from soybean cake or fishmeal as a whole, with exceptionally good results in production<sup>(8)</sup>. According to some authors, common duckweed reaches protein levels of up to 38 % of its biomass. This protein contribution and its ease of cultivation has allowed trials as feed for domestic ducks, obtaining results in weight gain and egg production comparable to the usual protein supplement, with the advantage of a 25 % decrease in feed costs in Asian countries<sup>(33)</sup>.

Other agricultural models have implemented common duckweed as a fodder crop for livestock raising, considering that common duckweed biomass has a protein content of more than 30 % of dry weight, representing an excellent complement in the feed of farmed animals, environmental sustainability, and cost reduction<sup>(34)</sup>. When it is used as the only source of nutrition, at a rate that should not exceed 6 % of body weight (dry basis), the results are much lower than those obtained with conventional diets, at which point they cease to be potentially beneficial; however, experiences in polycultures have shown that common duckweed supplementation increases production per hectare<sup>(8)</sup>. In this way, for more than 50 years, science has studied the different alternatives that common duckweed represents in the nutrition of different species of animals for consumption, yielding promising results as it is a rich and sustainable source of protein.

Now, some research on feeding dry common duckweed, *Lemna minor*, as a protein source in the diet of common carp fry, has shown that there are no significant differences in the growth and development of fish that are fed diets supplemented with up to 20 % common duckweed versus commonly used fish protein fodder. Showing that a diet consisting of up to 20 % common duckweed content could be used as a complete replacement for commercial feed in the formulation of the diet for common carp fry, allowing cost reduction<sup>(40)</sup>.

According to research carried out by Goswani *et al*<sup>(41)</sup>, when evaluating the impact of protein from dry common duckweeds (*L. minor*) compared to the impact of the standard and commercial diets of the fry of rohu *Labeo rohita* (carp native to the rivers of India and Asian regions), slight modifications in the digestive enzymatic activity of fish were identified. The diet with protein from common duckweed stimulates amylase, trypsin, and chymotrypsin activities, which were significantly higher compared to other diets, but without altering or modifying the growth rate of the fish. In this sense, the inclusion of raw common duckweed in the feed, replacing amounts of up to 30 % of fishmeal in the diet, can be well tolerated by farmed fish without affecting growth<sup>(42)</sup>.

In the case of farmed fish for human consumption, recent studies have researched the transfer of toxic heavy metals, such as cadmium, from common duckweed (*Lemna minor*) to freshwater tilapia (*Oreochromis mossambicus*). Through regression analysis, significantly positive correlations were found between the concentration of cadmium in common duckweed and freshwater tilapia meat, concentrations that were especially found in greater quantity in the tissues of intestine, edible muscle and remains. From this perspective, the analyses suggest the assessment of toxicity risks<sup>(40)</sup>. Other studies have researched the potential of common duckweed as an animal feed through the fermentation process with the addition of two probiotic strains, *Bacillus strains*, and *B. subtilis*, which have demonstrated health benefits for poultry, demonstrating that common duckweed is a promising alternative resource and has the opportunity to become a valuable resource in multiple industries such as that of foods, biofuels, pharmaceuticals, and wastewater phytoremediation. With the potential to increase sustainability, food security and reduce environmental impact<sup>(43)</sup>.

### **Environmental impact of common duckweeds**

With industrialization and the increase in the production of needs on a large scale by society, the pollution of both surface and underground water bodies has become a major problem with environmental and social impact<sup>(44)</sup>. The accumulation of numerous toxic substances in waters has led to the search for inexpensive and reachable options that allow to identify the level of toxicity that these natural spaces may have. Thus, the recent use of common

duckweed (*Lemna minor* and *Lemna gibba*) crops has made it widely possible to analyze the toxicity transmitted by water to organisms higher in the biological chain (animals and humans)<sup>(45)</sup>.

Other studies where growth parameters and assessment criteria, such as pigment content, peroxidase activity, lipid peroxidation and alkaline comet assay, were used to detect the toxic and genotoxic effects of surface water samples in common duckweed plants were able to indicate the ability of selected biomarkers to predict the phytotoxic and genotoxic effects of complex water mixtures on living organisms, as well as the relevance of common duckweed as a sensitive indicator of water quality<sup>(46)</sup>.

The inhibition of growth and reduction in the photosynthetic pigment of this plant when growing in polluted water environments have allowed its use as an effective biomarker in the non-specific detection of toxic components in water bodies. However, it should be recognized that although it is a good indicator of water pollution, common duckweed does not allow the nature of the agents or substances responsible for such toxicity to be determined by itself<sup>(47)</sup>.

Recent studies, despite the impossibility of identifying these toxic agents from common duckweed, have managed to document the adaptive capacity they have to metabolize some of these substances, such as nickel and ammonia, bringing the quality of water bodies to acceptable levels in a prudent time, a process known as phytoremediation of water bodies<sup>(48)</sup>.

Aquatic plants have been shown to be highly efficient in removing organic and inorganic pollutants<sup>(49)</sup>. *Lemna minor* has been widely applied for the remediation of various chemical contaminants. The plant is used separately or in combination with other aquatic macrophytes as an ecologically based pollution treatment technology<sup>(50)</sup>. *L. minor* has been reported as a floating microphyte highly successful for the phytoremediation of organic pollutants; it was the most effective plant in the treatment of wastewater for the remediation of municipal effluents. There was 98.8 % removal for total nitrogen and phosphorus, with a higher level of oxygen dissolution due to an improvement in nutrient loading by common duckweed<sup>(51)</sup>. Common duckweed has shown great potential for phytoremediation of organic pollutants, heavy metals, agrochemicals, pharmaceuticals, personal care products, radioactive waste, nanomaterials, petroleum hydrocarbons, dyes, toxins, and related contaminants<sup>(50)</sup>. Substances that pose a serious risk to the environment and all forms of life because they can be persistent, are easily transported through the media, and can cause poisoning of tissues and organs<sup>(52,53,54)</sup>. Tufaner<sup>(55)</sup> reported more than 90 % removal of heavy metalloids (chromium, zinc, aluminum, arsenic, cadmium, cobalt, copper, lead, and nickel), while 83 % for mercury in a mixture of wetland with *L. minor*. On the other hand, *Lemna minor* shows an increase in chromium absorption percentage of 6.1, 26.5, 20.5, and 20.2 % at a different exposure concentration of chromium stress<sup>(56,57)</sup>. In addition, research conducted in relation

to agricultural chemicals such as fertilizers, pesticides, herbicides, and fungicides shows that common duckweeds can accumulate and degrade these agrochemicals<sup>(58,59,60)</sup>. Common duckweed has the ability to conserve nature by acting as a hyperaccumulator. The wide application of the plant is due to its ubiquitous nature, invasive mechanism, sporadic reproductive capacity, bioaccumulation potentials and resilience in polluted environments<sup>(61)</sup>.

### **Toxicity and antinutritional substances**

Studies have highlighted the presence of antinutritional components, substances, or factors in common duckweed<sup>(3)</sup>. After several toxicity tests, it was discovered that common duckweeds are extremely sensitive to triazines, sulfonylureas and pyridines, compounds currently classified as toxic with a great polluting impact on the environment and that, given the way of nutrition of this plant, they can absorb them. However, many authors point out that the amounts of these compounds in this plant are small, and that they could be susceptible to denaturation when subjected to heat treatments<sup>(62)</sup>.

Antinutritional factors are substances or compounds that have the ability to interfere with the biological use or exploitation of a food or nutrient, affecting a person's health and some or more of the physiological processes of the body. Some authors have reported the presence of tannins and phytic acid in common duckweeds in concentrations of 0.02 and 0.09 %, respectively<sup>(63)</sup>.

Likewise, other studies showed concentrations of trypsin inhibitors at 1.47 %, calcium oxalates at 3.5 % and tannins in concentrations much higher than previously cited studies, 0.9 %<sup>(64)</sup>. However, recent research has highlighted low concentrations of cyanide at 0.15 %, phytic acid 0.58 %, and tannins 0.48 % when analyzing a wide variety of common duckweed strains; likewise, these samples were subjected to heat treatments where the deactivation or inhibition of these substances was evidenced, thus eliminating the toxicity that could be implied by the consumption of the plant<sup>(65)</sup>.

According to research carried out by Sree *et al*<sup>(66)</sup> to determine the cytotoxic effects and antiproliferative activity in human cell lines of several common duckweed species, including *L. minor*, it was found that whole plant extracts do not have any detectable adverse effect in human cell lines, which is a step towards ensuring the global use of common duckweed as a component of human nutrition.

## Conclusions

In recent years, common duckweed has taken on a prominent role in biotechnology and agricultural applications. It could potentially be an important resource as an alternative source of food for humans and animals. It has been used as raw or processed feed for meal production, making it interesting in the animal feed industry, aquaculture, health supplements, biofertilizers, biofuels, and emerging human food products.

It has demonstrated its strong potential for phytoremediation of organic pollutants, heavy metals, agrochemicals, pharmaceuticals, personal care products, radioactive wastes, nanomaterials, petroleum hydrocarbons, dyes, toxins, and related contaminants. The wide application of the plant is due to its ubiquitous nature, invasive mechanism, sporadic reproductive capacity, bioaccumulation potentials, and resilience in polluted environments.

The nutrients in the water in which it is grown critically affect its nutritional value, so it will likely need to be decontaminated before feeding the animals if there are heavy metals in the water, since common duckweed concentrates them. In this sense, it is important to highlight the scarcity of studies on the use of these plants in human nutrition; therefore, it is necessary to continue research to determine the role they could take and be included in the human diet and the safety associated with their continuous consumption, large-scale yield, economic market supply and sustainability.

Despite the challenges and knowledge gaps, there are realistic opportunities to develop and operate controlled, autonomous, high-capacity common duckweed crops under indoor conditions, for a wide range of purposes that ensure the characteristics of the final product. It should be noted that accelerated growth, the impact of climate change, the decrease in arable land, the depletion of soil, nutrients and water supply make it increasingly difficult to obtain quality food in the quantities required.

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