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Macrophytes - Features, Chemical Properties and Problems of Industrial Cultivation

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A B S T R A C T

This research study systematically examines the role of macrophytes (higher aquatic plants) in the economy, their advantages over other resources, and the existing challenges in their cultivation and product development processes. Additionally, the nutritional value of widely used macrophytes such as *Eichhornia crassipes, Pistia stratiotes, Azolla caroliniana*, and *Lemna minor*, which are extensively cultivated in agricultural wastewater under Uzbekistan's conditions, is highlighted.

Introduction

Worldwide, extensive research is being conducted to utilize macrophytes as an effective source for the production of food and feed products (Wasagu *et al.,* 2013; Leterme *et al.,* 2009; Landolt *et al.,* 1987). Macrophytes are widely distributed in tropical and subtropical climatic conditions and are now being cultivated both naturally and artificially in various climatic regions around the world (Xurshidbek O. Abdullayev *et al.,* 2023).

Several factors are cited as reasons for the large-scale cultivation of macrophytes worldwide:

First, macrophytes are considered highly important in various sectors of the economy. In particular, higher aquatic plants play a crucial role in the biological treatment of industrial wastewater by removing pollutants (Tarkowska-Kukuryk *et al.,* 2022).

Second, macrophyte cultivation is relatively easier compared to other sources. They are highly resistant to external environmental factors, including pests and diseases, and are characterized by rapid growth and reproduction.

Third, macrophytes have a unique chemical composition. They are rich in proteins and contain a complete profile of essential amino acids. Additionally, although present in small amounts, their lipid content includes essential fatty acids, along with vital macro- and microelements (Xurshidbek O. Abdullayev *et al.,* 2023).

Fourth, macrophytes can be cultivated using a monoculture approach, allowing for the separate and controlled production of specific species;

Fifth, macrophyte biomass can be used not only for food and feed production but also as green fertilizer in agriculture;

Sixth, cultivating macrophytes in aquaculture ponds helps regulate water salinity, enrich water with oxygen, and enhance the survival of live feed organisms such as zooplankton (Hasanboy Abdinazarov *et al.,* 2023a).

Analysis of scientific sources and the macrophyte cultivation process reveals that, in addition to their beneficial properties, there are several unresolved challenges associated with their use, including:

First, during the cultivation of macrophytes in natural water bodies or wastewater from industrial enterprises, the water composition is often chemically imbalanced. Additionally, factors such as fluctuations in pH levels, unstable temperatures, and insufficient dissolved oxygen content can hinder the production of high biomass yields.

Second, when macrophytes are cultivated in uncontrolled wastewater reservoirs, the presence of chemically undefined elements, the inability to regulate their stable concentrations, fluctuations in water depth, and insufficient sunlight exposure can lead to poor growth or necrosis. As a result, achieving both sufficient biomass production and a stable chemical composition of the biomass becomes challenging. Third, like all plants, macrophytes grow best in a stable chemical environment. However, when cultivated in wastewater reservoirs, the high concentration of mineral salts promotes the excessive growth of microalgae and other free-floating higher aquatic plants. This intensifies competition for nutrients between macrophytes, microalgae, and other aquatic vegetation, making it difficult to produce macrophyte biomass with a consistent chemical composition (Hasanboy K. Abdinazarov *et al.,* 2023b).

Fourth, in uncontrolled conditions, macrophyte cultivation often relies on irrigation water from rivers and canals, seepage water formed after plant irrigation, or technical wastewater from various industrial enterprises. As a result, sudden changes in river flow, unstable salt concentrations in seepage and technical waters, and high levels of heavy metals and toxic elements can significantly limit the usability of macrophyte biomass for intended products or as feed (Musurmonov *et al.,* 2021).

Fifth, in uncontrolled conditions, standardizing the biomass and establishing sanitary-hygienic indicators becomes challenging. This prevents clear recommendations for using the biomass in specific industries. For example, poultry farming requires microbiological and sanitary standards, while agriculture demands regulatory and technical certifications regarding the content of heavy metals, chlorinated organic compounds, and toxic elements (Shakirov *et al.,* 2014).

To overcome the challenges associated with macrophyte cultivation, it is advisable to grow them under controlled conditions. This requires several key measures, including: developing an optimal nutrient medium composition for macrophytes, studying the impact of the physical parameters of water bodies on biomass production, and establishing technical and economic indicators for efficient cultivation.

This study aims to determine the primary nutritional values of certain macrophytes cultivated in agricultural wastewater under the conditions of Uzbekistan.

Materials and Methods

Used biological objects

Macrophyte samples cultivated in agricultural wastewater were collected during June and July of 2023–2024. The following macrophyte species were used as biological objects: Eichhornia crassipes (Family: Pontederiaceae), Pistia stratiotes (Family: Araceae), Azolla caroliniana (Family: Azollaceae), and Lemna minor (Family: Araceae).

The samples were dried at room temperature. Before drying, they were thoroughly washed three times with tap water and twice with distilled water to ensure the removal of foreign plants and any additional contaminants.

Lipid determination

The lipid analysis of macrophytes was carried out using conventional methods. Ethanol was used as an organic solvent, and lipid extraction was performed using a Soxhlet apparatus. The lipid content was then calculated as a percentage of the dry biomass.

Carbohydrate determination

To quantify the total carbohydrates, the dried macrophyte biomass was ground to a particle size of up to 1.0 mm in diameter.

Protein determination

The total protein content of macrophytes was determined using the conventional Bradford method and analyzed with a microplate spectrophotometer (Bradford, 1976).

Statistical analysis

The calculation of statistical error, mean, reliability intervals and standard deviations to the experimental data was performed using the computer program STATISTICA 6.0 and standard methods. The statistical significance of the results was determined using the Student t-criterion.

Results and Discussion

During their research, the nutritional value of macrophytes grown in local conditions using agricultural wastewater was studied (table). When analyzing the results, it was noted that the average protein content of the azolla macrophyte was 23.51% relative to dry weight.

It was found that the average protein content of the pistia macrophyte relative to dry weight was 13.50%, the eichhornia macrophyte was 18.28%, and the small duckweed was 20.08%.

When analyzing the results obtained, it was noted that the macrophyte Azolla stored 10.01% more protein than Pistia, 4.23% more protein than Eichornia, and 3.43% more protein than Lesser Dandelion.

According to the results of the analysis, it was found that Azolla has a slightly higher protein content among macrophytes naturally growing in agricultural wastewater. According to the results of the analysis of lipid content of macrophytes naturally growing in agricultural wastewater, Azolla stored 3.78% lipid, while Pistia stored 2.58% fat. Under these conditions, Eichornia stored 7.55% fat, and Lesser Dandelion stored 2.58%.

When analyzing the results, it was noted that among macrophytes, eichhornia showed good indicators in terms of high fat content. When comparing macrophytes in terms of fat content, it was found that azolla contained 3.78% fat, pistia 2.58%, eichhornia 7.55%, and small ryaka 2.58% fat in relation to dry mass. It was found that eichhornia contained 3.77% more fat than azolla, and 4.97% more fat than pistia and small ryaka.

Lipid analysis of macrophytes was carried out using conventional methods. In particular, alcohol (ethanol) was used as an organic solvent, and it was calculated in relation to oil yield from dry biomass in a Soxhlet device.

It is appropriate to look at the level of reliability of the research results only in relation to ethanol, which was used as an organic solvent. It is known from scientific sources that oil release from macrophytes can be altered in other types of organic solvents, such as ethyl acetate and hexane.

Our research was based on the results of the macrophyte production of oil in alcohol. Therefore, it is advisable not to accept the results of this research as a final conclusion. Therefore, according to the results of extraction based on ethanol, Eichhornia macrophyte shows a higher index compared to other macrophytes. When analyzing the results of the research shown in the table, it was found that the amount of total carbohydrates was 44.18% in azolla, 58.19% in pistachio, 50.16% in eichhornia, and 43.59% in small ryaska.

When comparing the obtained results, it was noted that the total carbohydrate content of pistia is 14.01% higher than Azolla, 8.03% higher than Eichhornia, and 14.50% higher than small ryaska.

Table.1 Comparative Analysis of the Nutritional Values of Locally Cultivated Macrophytes (in % relative to dry mass)

Macrophyte	Experience examples	Average protein storage	Moderate lipid storage	Total carbohydrates	Number of usable elements
Azolla	A1	28,14	4,33	42,18	15,02
	A2	20,23	3,58	46,11	16,24
	A3	26,58	4,21	46,08	18,5
	A4	20,32	3,26	44,36	16,54
	A5	23,22	3,51	44,15	17,24
	A6	24,43	4,16	44,18	18,23
	A7	21,67	3,43	42,23	15,42
Average indicator		**23,51**±0,37	**3,78±0,35**	**44,18±0,18**	**16,74±0,31**
Pistia	П1	11,8	2,31	53,47	17,23
	П2	17,23	2,17	60,18	15,62
	П3	13,27	3,11	59,48	16,43
	П4	12,43	2,42	59,36	17,23
	П5	13,14	2,71	58,11	16,37
	П6	14,21	3,14	57,24	16,48
	П7	12,43	2,23	59,48	17,23
Average price		**13,50±0,36**	**2,58±0,30**	**58,19±0,33**	**16,66±0,37**
Eichornia	Э1	17,93	8,23	49,23	12,12
	Э2	18,02	6,41	49,37	12,76
	Э3	17,48	8,23	48,16	12,84
	Э4	18,37	7,18	50,22	14,08
	Э5	20,34	6,14	49,62	14,92
	Э6	18,18	8,23	48,13	16,18
	Э7	17,62	8,42	56,42	15,26
Average price		**18,28±0,42**	**7,55±0,26**	**50,16±0,31**	**14,02±0,45**
duckweed	P1	20,23	3,23	43,26	23,13
	P2	18,86	2,82	41,13	21,31
	P3	19,23	2,56	43,54	21,24
	P4	20,37	2,78	44,18	23,08
	P5	21,42	2,24	45,12	20,12
	P6	20,28	2,18	43,37	21,08
	P7	20,18	2,27	44,52	22,23
Average value		**20,08±0,37**	**2,58±0,44**	**43,59±0,30**	**21,74±0,17**
Explanation: **all samples are macrophyte samples growing in agricultural wastewater (sewage); n=5.**					

When we compared macrophytes according to their nutritional value, it was noted that Azolla showed a high index in terms of protein storage, while Pistia showed a high index in terms of total carbohydrate storage. It is known from scientific sources that macrophytes with a high content of total carbohydrates are easy for animals to assimilate, but their demand for nutrients is not fully met.

Also, technological difficulties arise in the storage and processing of sources with a high content of carbohydrates. Therefore, more emphasis is placed on sources with a relatively high protein content and a relatively low content of total carbohydrates. Therefore, it is advisable to focus on azolla, which has a relatively high protein content compared to macrophytes. Based on subsequent studies, the total organic matter content of macrophytes was determined (table). According to the results obtained, it was noted that azolla contains 16.74%, pistachio 16.66%, eichhornia 14.02%, and small duckweed 21.74%. When analyzing the results obtained, it was noted that eichhornia contains a very small amount of organic matter. Due to the low content of this indicator compared to other macrophytes, scientific analyses were conducted. According to scientific analysis, deep elemental analysis conducted by Chinese scientists (Huang *et al.,* 2018) showed that the ash content of eichhornia is on average 16.35% by mass, while studies conducted by Indonesian scientists concluded that the dry mass is enriched with C, O, and Cl relative to the wet biomass, and that the main ash elements are more than 1%, while the secondary ash elements (1-0.1%) and ash-forming elements are more abundant (Sukarni *et al.,* 2018).

In a scientific article published in 2019 by Sukarni and his colleagues, it was noted that the content of total elements in the macrophyte Eichhornia is around 20.1% (Sukarni Sukarni *et al.,* 2019). Studies conducted by Nepalese scientists also showed that the average content of total elements in Eichhornia is 16.79% by mass (Tham, 2015; Tiwari *et al.,* 2020). Therefore, the results obtained during our research can be considered as close to the true experimental results. Based on the above experimental studies, it was found that the chemical composition of macrophytes is rich in chemical substances with nutritional value. By comparing the results obtained in the studies, azolla was selected as the most optimal source of protein among the studied macrophytes. Based on the studies conducted, azolla was noted as a highly effective object among the studied macrophytes in terms of protein storage relative to dry mass. However, it was noted that azolla has a lower index of storage of other important chemical substances, including lipid storage, compared to eichhornia. It is known from scientific sources that when selecting macrophyte species with high nutritional value, the main attention is paid to their protein storage and, at the same time, a relatively low fiber content. The data obtained show that the high protein storage and relatively low fiber storage of azolla compared to other macrophytes served as the basis for choosing this tall alga as the object of our research. Further research is needed to develop optimal nutrient medium composition for macrophyte cultivation under controlled conditions, to study the effect of physical parameters of macrophyte cultivation ponds on biomass production, and to develop technical and economic indicators.

Author Contributions

Gulirukhsor V. Akbarova: grown the macrophytes and analyzed samples. Alvina Farooqui: Formal analysis, writing - review and editing. Tripathi Gyanendra: Investigation, formal analysis, writing - original draft. Nortoji A. Khujamshukurov: conceptualization, data curation, investigation, methodology, supervision, validation, writing - original draft, writing - review & editing.

Data Availability

No data was used for the research described in the article.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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