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RESEARCH ARTICLE
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Intensive Cultivation of Vascular Aquatic Plants in the Conditions of the Central Regions of Uzbekistan and Preparation of Feed for Herbivorous Fish

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ABSTRACT

The study focuses on the intensive cultivation of *Azolla caroliniana* L. and *Lemna minor* L. using wastewater from residential complexes to achieve high biomass productivity. The results of the analysis indicate that the obtained biomass, due to its high content of protein and nutrients, can be widely in demand as high-quality, economical, and environmentally friendly feed for freshwater fish. Azolla and Duckweed, in addition to effective water purification, provide a significant biomass yield per square meter and create an optimal nutrient medium for feed production. The produced biomass significantly enhances the efficiency of fish feed and contributes to increased economic benefits in the fish industry. The prospect of successful use of plant biomass generated in the process of biological wastewater treatment as fish feed contributes to environmental protection and rational waste management, which is both a scientific novelty and of practical significance.

Keywords: White amur fish, Duckweed, Azolla, Water temperature, Natural food, Growth rate

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INTRODUCTION

A pressing global concern revolves around the detrimental effects of wastewater on ecosystems. In Samarkand, the volume and characteristics of wastewater pose a direct threat to both ecological stability and the health of fisheries. Addressing this issue requires exploring avenues for not only disinfecting wastewater but also transforming it into valuable biological resources through recycling processes. Research has highlighted the potential of fast-growing aquatic plants with tolerance to pollution and inherent purification capabilities, specifically *Azolla caroliniana* L. and *Lemna minor* L. These plants offer a natural means of purifying water bodies, and their resulting green biomass presents an inexpensive and nutritious feed source for livestock and aquaculture. Our research investigated the feasibility of cultivating *Azolla* and *Lemna* using wastewater sourced from Samarkand. Experiments were conducted at the laboratories of the Department of Medicinal Plants and Food Technology at the Samarkand Institute of Agro-Innovations and Research, alongside water composition analysis performed at the Samarkand Regional Department of the Committee for Ecology and Environmental Protection. The study meticulously analyzed the impact of varying dilutions of wastewater on the growth of Azolla and Duckweed, alongside key physicochemical parameters and the plants' biomass production rates. Scientific research aims to optimize biological wastewater treatment processes, determine the growth and biomass productivity of aquatic plants, and identify the potential of their practical use as an additional feed in fisheries. The study shows that intensive cultivation of low-growing aquatic plants, especially wheat, to provide food for herbivorous fish such as carp and grass carp, will lead to increased production, focusing on sustainable aquaculture practices. The study emphasizes the ecological advantages of cultivating fast-growing aquatic plants, which improve

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fish production while purifying water bodies and reclaiming agricultural lands. It details the formulation and production techniques for three types of fish feed, demonstrating their effectiveness in pond farming environments. This strategy promotes environmentally conscious aquaculture and fosters the growth of a new market segment centered on eco-friendly feed manufacturing (Skokov et al., 2023). Another investigation reveals that cultivating aquatic plants can provide a significant nutritional foundation for herbivorous fish, especially when these plants undergo processing to minimize antinutritional elements. The fermentation of aquatic macrophytes, such as *Lemna* and *Spirodela*, enhances their digestibility and boosts the availability of essential nutrients. Incorporating these fermented plants into diets with reduced fish meal content has a positive impact on the growth performance of species like Piaractus brachypomus, positioning them as a practical alternative feed option for small-scale aquaculture operations (Velásquez, 2016). Furthermore, research examines the application of *Lemna* sp. as a feed alternative for herbivorous fish like Nilem (*Osteochilus vittatus*) and Tawes (*Barbonymus gonionotus*). The intensive farming of *Lemna* sp. has the potential to lower operational expenses and increase the income of fish farmers. It can be administered in fresh, dried, or fermented states, contributing to sustainable aquaculture practices. The integration of *Lemna* sp. into farming systems promotes efficient feed processing and supports the overall sustainability of fish farming endeavors (Iskandar et al., 2020). The paper does not specifically address the intensive cultivation of higher aquatic plants for herbivorous fish feed. It focuses on high-protein plant components, particularly soybeans and corn, as supplements in aquaculture feeds for fish. These ingredients are highlighted for their protein content and affordability, but the study does not explore the cultivation of aquatic plants or their role in feeding herbivorous fish (Tkacheva et al., 2024). The paper highlights the potential of utilizing higher aquatic plants, such as *Lemna Minor* and *Water Hyacinth*, as feed for herbivorous fish. Intensive cultivation of these plants can provide a sustainable and cost-effective feed source, enhancing fish growth while reducing reliance on commercial feeds. The integration of these plants into fish farming not only ensures stable feed availability throughout the year but also contributes positively to environmental sustainability by improving water quality and minimizing negative ecological impacts (Pratiwy et al., 2024). The paper does not specifically address the intensive cultivation of higher aquatic plants for feed preparation for herbivorous fish. It focuses on semi-intensive fish culture, pond fertilization, and the integration of tilapia with other farming systems (El-Sayed, 2020). The paper focuses on intensive fish culture systems, primarily discussing complete feeds for carnivorous fish. It does not specifically address the intensive cultivation of higher aquatic plants for herbivorous fish feed preparation (*Complete Feeds—Intensive Systems*, 2022). The sheep readily ingested the fresh or dried Duckweed. None of the wool measures (yield, rate of fibre elongation, fibre diameter) differed ($p>0.05$) between dietary treatments. In Experiment 2, oaten-chaff-based diets (800g/d) supplying 6.5-7.2MJ (1.6-1.7Mcal)/d of ME were supplemented with iso-nitrogenous amounts (4-5g N) of either urea (8g), cottonseed meal (60g), or dried Duckweed (100g). In this experiment, the rate of wool fiber elongation, thought to be related to intestinal amino acid absorption, was lower ($P<0.05$) for sheep given the oaten chaff/urea diet than for those given either oaten chaff/cottonseed meal or oaten chaff/duckweed for which the rates did not differ ($P>0.05$) (Nolan et al., 2001). The isolation procedure resulted in a large enrichment in RuBisCO (from 48% to 92%). Denaturation of duckweed protein concentrate was observed at 62°C at pH 7, while heating at pH 4 did not show denaturation peaks. Solubility was good far from the isoelectric point and showed a minimum around pH 5. Gelling was better at pH 7 than at pH 4. At pH 7, duckweed gels were much stronger than soy and only slightly weaker compared to egg white protein, while at pH 4, duckweed gel strength was similar to soy and lower than egg white (Nieuwland et al., 2021). This review highlights the nutritional potential of the seaquatic species, focusing on their high protein content, rapid growth rates, and adaptability to non-arable environments. Microalgae, such as *Chlorella* and *Arthrospira* spp., and Duckweed, such as *Lemna minor*, are evaluated for their functional food applications, including their roles as protein supplements, bioactive components, antioxidants, and emulsifiers in food formulations. The study also examines their environmental benefits, including wastewater bioremediation, nutrient recycling, and greenhouse gas mitigation, which contribute to a more sustainable agricultural system. Technological advancements in the cultivation, harvesting, and processing of microalgae and Duckweed are discussed to enhance their scalability and economic feasibility in food and feed production (Song et al., 2025). The present study investigates the effect of processing methods (pH shift processing, autoclaving, microwaving, and blanching) on the physicochemical, functional, antinutritional, antioxidant properties and mineral characteristics of *Azolla pinnata powder*. Results showed that processing treatment significantly ($P<0.05$) influenced the quality of *Azolla* powder. Blanching significantly decreased the protein, ash, and fiber content (Kaur et al., 2024). Various plant-based materials effectively absorb oil contaminants at the water/air interface. These materials showcase unparalleled efficiency in purging oil contaminants, encompassing rivers, lakes, and boundless oceans, positioning them as integral components of environmental restoration endeavors. In addition, they are biodegradable, readily available, and eco-friendly, thus making them a preferable choice over traditional oil cleaning materials. This study explores the phenomenal properties of the floating Azolla fern (*Azolla pinnata*), focusing on its unique hierarchical leaf surface design at both the microscale and nanoscale levels (Mohd et al., 2024). The use of nano- and microparticles as a release system for agrochemicals has been increasing in the agricultural sector. However, the production of eco-friendly and smart carriers that can be easily handled in the environment is still a challenge for this technology. In this context, we have developed a biodegradable release system for the herbicide atrazine with magnetic properties. Herein, we investigated the (a) physicochemical properties of the atrazine-loaded magnetic poly (ε-caprolactone) microparticles (MPs: ATZ), (b) in vitro release kinetic profile of the herbicide, and (c) phytotoxicity toward photosynthesis in the aquatic fern *Azolla caroliniana* (Forini et al., 2020). This research identified and characterized factors that influenced nanomaterial bioavailability to three aquatic plants: *Azolla caroliniana* Willd, *Egeria densa Planch*, and *Myriophyllum simulans* Orch. Plants were exposed to 4-nm, 18-nm, and 30-nm gold nanoparticles. Uptake was influenced by nanoparticle size, the presence of roots on the plant, and dissolved organic carbon in the media (Glenn and Klaine 2013). In this work, a miniaturized and disposable electrochemical sensor was developed to evaluate the cadmium and lead ion phytoremediation potential of the floating aquatic macrophyte *Lemna minor* L. The sensor is based on a screen-printed electrode modified "in situ" with bismuth film, which is more environmentally friendly than the mercury-based sensor usually adopted for lead and cadmium ion detection (Neagu et al., 2014). Uptake and transformation of ^{14}C-labeled metabolites from several pesticides, 3-methy l-4-*nitrophenol* (1), 3,5-*dichloroaniline* (2), 3-*phenoxybenzoic acid* (3), (*R*, *S*)-2-(4-*chlorophenyl*)-3-*methylbutanoic acid* (4), and (1*RS*)-*trans*-3-(2,2-*dichlorovinyl*)-2,2-*dimethylcyclopropanecarboxylic acid* (5), were examined by using Duckweed (*Lemna gibba*) in Hoagland's medium (Fujisawa et al., 2006). However, habitat degradation and vegetation cover loss have been exacerbated by high human pressure and prolonged droughts driven by climate change (Bobokandov et al., 2024a; 2024b). The uptake and phytotransformation of organophosphorus (OP) pesticides (*malathion, demeton-S-methyl, and crufomate*) were investigated in vitro using the axenically cultivated aquatic plants parrot feather (*Myriophyllum aquaticum*), Duckweed *(Spirodela oligorrhiza* L.), and elodea *(Elodea canadensis*). The decay profile of these OP pesticides from the aqueous medium adhered to first-order kinetics (Gao et al., 2000). Uzbekistan's slightly salinized soil conditions. The following characteristics of adaptability were identified (Isomov et al., 2025). It was found that the raw material biomass and dry matter content of the plant grown under artificial shade were significantly higher than that of the plant grown under direct sunlight (Hamrayeva et al., 2025). Two experiments were carried out to investigate whether Duckweed is useful as a dietary protein source for fine-wool Merino sheep and to evaluate its effects on wool yield and characteristics. In Experiment 1, the sheep were given one of three maintenance diets consisting of oaten chaff (520-700g/d) supplemented with 16-32g crude protein/d in the form of fresh (1kg/day) or sun-dried (50-100g/d) Duckweed (Nolan et al., 2001). Duckweed is considered a promising source of protein for human food products due to its high protein content and environmentally friendly production properties. In order to achieve successful inclusion in the diet, Duckweed should be presented to consumers in a way that is acceptable to them. This paper explores Western consumers' perceptions towards Duckweed as human food and investigates in what contexts duckweed could be acceptable to consumers who are not used to eating it. In a first interview study (N=10), consumers generally responded positively towards Duckweed as human food, although associations with turbid ponds also did come up. According to the respondents, Duckweed was classified as a vegetable. So, Duckweed was considered to fit best in meals where vegetables and greens are expected. In a larger online survey (N=669), it was confirmed that consumers had a more positive deliberate evaluation of Duckweed and were more likely to accept a meal with Duckweed if Duckweed was applied in a fitting meal (De Beukelaar et al., 2019). Over the past 50 years, different strategies have been developed for the remediation of polluted air, land, and water. Driven by public opinion and regulatory bottlenecks, ecological-based strategies are preferable to conventional methods in the treatment of chemical effluents. Ecological systems with the application of microbes, fungi, earthworms, plants, enzymes, electrodes, and nanoparticles have been applied to varying degrees in different media for the remediation of various categories of pollutants (Ekperusi et al., 2019). Invasive alien plant species are usually characterized by a growth rate higher than their native competitors, and this higher rate can be achieved through the opportunistic use of plant nutrients. The growth of the invasive alien Duckweed *Lemna minuta* and the co-generic native *Lemna minor* were compared under different conditions of nutrient availability (Paolacci et al., 2016). Duckweed *Lemna minor* was cultivated in human urine (HU), and the effect of urine type, dilution factor, temperature, and the existence of macro- and microelements on growth rate was investigated. The simultaneous removal of nutrients and selected antimicrobials was also studied in experiments with HU and treated domestic wastewater, while the starch and protein content of biomass was determined (Iatrou et al., 2015). In this study, wastewater blended from textile, distillery, and domestic sources at a corresponding volumetric ratio of 3:1:18 was treated using *Lemna minor* and *Azolla filiculoides* for 28 days in a batch system installed in a shade house. Analysis of variance between the two macrophytes showed no statistical differences in removals of all tested parameters ($P<0.05$) except for the biochemical oxygen demand, where removal was higher in the *L. minor*. Electrical conductivity, pH (Amare et al., 2018). This study concentrated on utilizing a novel heterogeneous dolomite catalyst in the transesterification of *Azolla pinnata* algae oil with methanol to convert *Azolla pinnata* methyl ester (AME). XRF, XRD, FTIR and BET analysis characterized the thermophysical properties of the catalyst. The optimized AME yield of 88.7% was obtained for the methanol to oil molar ratio (30:1), catalyst weight% (4 wt%), and operating temperature of 70°C through central composite design (CCD) in response surface methodology (RSM) technique (Prabakaran et al., 2021). A high protein content combined with its enormous growth capacity makes Duckweed an interesting alternative protein source, but information about postprandial responses in humans is lacking. The present study aimed to assess the postprandial serum amino acid profile of *Lemna minor* in healthy adults in comparison with green peas. A secondary objective was to obtain insights regarding human safety. A total of twelve healthy volunteers participated in a randomised, crossover trial (Zeinstra et al., 2019). This study aimed to determine the possibility of using Duckweed in sustainable livestock production and aquaculture. Duckweed is a small plant that grows in water and is exploited in biotechnology, dietetics, phytotherapy and ecotoxicology. It is also used for biological wastewater treatment, and for biogas and ethanol production. This study provides the characteristics of Duckweed and presents results indicating its applicability in livestock feeding (Sońta et al., 2019). In the present experiment, Duckweed was evaluated as a novel protein source for dogs by incorporating Landoltia punctata into dog diets at 10%, 20% and 30%. The inclusion of Duckweed resulted in significant ($P<0.001$) linear decreases in DM, gross energy, and crude protein digestibility. The addition of the exogenous enzyme phytase significantly ($P=0.03$) improved crude protein digestibility in the diet of 30% duckweed inclusion (Brown et al., 2013). The nutritional analysis results show that relative to the control, the ice cream with 2% dried *L. minor* had significantly increased protein, fiber, and ash content. In addition, total plate count (TPC) for microbial analysis of duckweed ice cream was performed. The result suggested that a small amount of bacteria (3.82cfu/g) was detected in formulated ice cream with 2% dried *L. minor*. Overall, the metabolite profile, nutritional, and microbial analyses of the food used *L. minor* plant indicate that Duckweed is a good candidate for future food (Yahaya et al., 2022). The number of monotypic and less polymorphic taxa has a relatively large proportion compared to the total algal flora, which indicates a high biodiversity of algal flora. The highest indicators of the coefficient of similarity of the species composition of the studied reservoirs were noted in the Karatepa reservoir, Amankutansai (0.4), and Kuzichisai (0.35). This is explained by the fact that both streams flow directly into the Karatepa reservoir (Dustov et al., 2024). Azolla has a high nutritional value compared to other aquatic plants because it is a source of protein with almost all the essential amino acids needed for animal nutrition. In the selected nutrient medium, the green mass of Azolla increased several times. Technical regulations have been developed for growing Azolla in different nutrient media in open conditions. The results of a chemical study of the green mass of Azolla showed that in the selected nutrient medium, the proportion of protein increased several times. This study analyzes the efficiency of feeding Nile tilapia with Azolla, an aquatic plant (Shernazarov et al., 2024). This article provides information about the growth, development, and multiplication of small Duckweed and medium-sized Duckweed and other poultry farms, as well as the exploration of cleaning water from pesticides and mineral fertilizers. This article discusses the growth of Duckweed, a type of water grass, in the foul water of poultry farms and its role in purifying water (Buriev et al., 2019). The results of using the nitrogen fixing symbiotic system *Azolla–Anabaena* to improve the quality of treated urban wastewater, particularly concerning phosphorus removal efficiencies (40–65%), obtained in continuous assays performed during the past few years and presented earlier, were very promising. Nevertheless, the presence of combined nitrogen in some wastewaters can compromise the treatment efficiency (Costa et al., 2009). This article focuses on the trophic levels of the two types of duckweeds (*Wolffia arrhiza* and *Lemna minor*). Using the development of the optimal modeling of the biological processes, we have obtained the prescriptions for individually-balanced culture medium that enable 3.0 times higher yields of the total soluble protein from each of the populations for both types of *Lemnaceae* (Khvatkov et al., 2019). The rate of AF fibre fermentation in the pig large intestine was measured using an *in vitro* gas test. The rates were much lower than tropical tree foliage, which can also be used in pig diets in the tropics. This could partly explain the low apparent digestibility of AFs in pigs. In conclusion, the inclusion level of AFs in rations for sows should be limited to 150g AFs kg^{-1} diet due to the low digestibility and energy density, as well as the negative impact on the digestibility of the whole diet (Leterme et al., 2010). Duckweed (*Lemnaceae*) is a fast-growing aquatic vascular plant. It has drawn increasing attention worldwide due to its application in value-added nutritional products and in sewage disposal. In particular, Duckweed is a promising feedstock for bioenergy production. In this review, we summarized applications of Duckweed from the following four aspects. Firstly, Duckweed could utilize nitrogen, phosphorus, and inorganic nutrients in wastewater and reduce water eutrophication efficiently (Liu et al., 2021). Analysis of available scientific sources shows that the biomass indices of vascular aquatic plants' organs. The main raw material in different periods of vegetation has not been studied. For the first time, studies were conducted on the impact of intensive cultivation of vascular aquatic plants on the growth and development of plants and biomass indices in the conditions of the central regions of Uzbekistan. Clear conclusions were drawn, and feed for herbivorous fish was prepared.

MATERIALS & METHODS

Study Site

As a result of experimental studies conducted in Samarkand in 2024-2025, the biomass efficiency of Azolla and Lemna plants growing in ponds was studied.

The study focused on three main areas: physicochemical analysis, plant cultivation in water bodies, and monitoring changes in water composition. During the experiment, Azolla and Lemna plants were grown in ponds under controlled conditions to evaluate biomass production and its impact on water quality (Fig. 1).

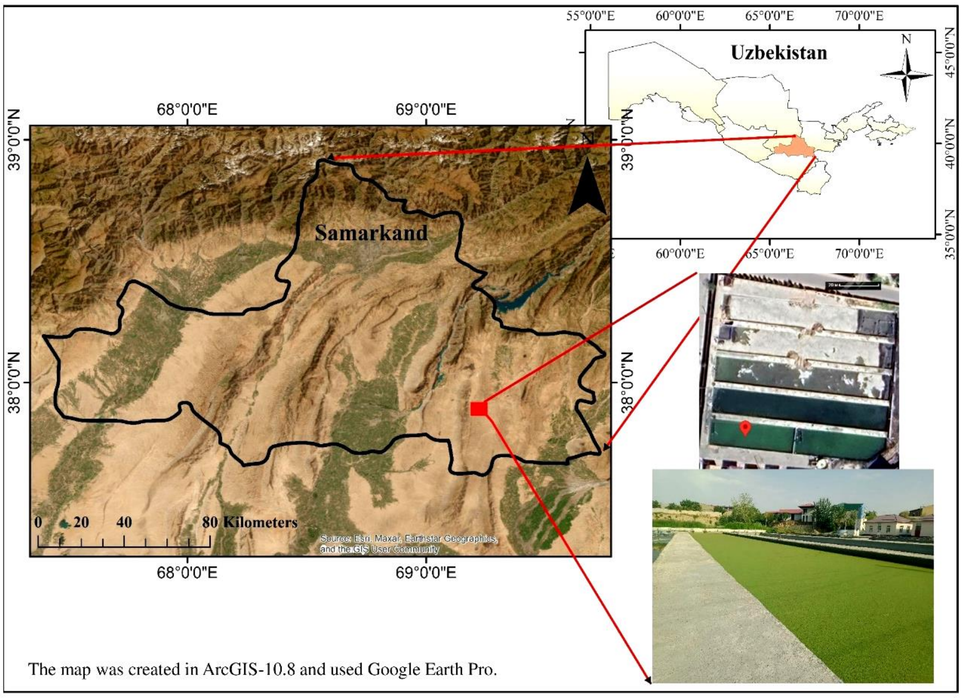

Fig. 1: Geographic location of the study area.

Methods

Conducted in 2024-2025, the following methods were used: 1) Physical and chemical analysis methods for the determination of water quality indicators (temperature, pH, color, odor, dissolved oxygen, heavy metals, OH, ammonia, nitrite, nitrate, sulfate, chloride). Water analysis was carried out in the laboratory of the Environmental Pollution Monitoring Department of the Samarkand Regional Department of Ecology and Environmental Protection. The analyses were carried out based on GOST and UzDST standards, 2) Experiments were conducted in Samarkand on the cultivation of *Azolla* and *Lemna* plants in wastewater. Growth dynamics, green biomass yield, and their effect on water composition were observed, and 3). The experimental method was carried out in 3 different ways: option: undiluted (clean wastewater) water. When determining the composition of undiluted wastewater, the temperature was -26.3°C, the color of the water was brownish-brown, the pH environment was 6.4, the odor was high, 5.2 points, suspended solids - 154.3mg/L, and the light was 10 thousand lux. The dissolved oxygen in the water was 2.2mg/L. When the Vaiant wastewater was diluted with a 1:1 ratio, that is, 50% wastewater and 50% tap water, the temperature remained constant at 26.3. The color of the water was light brownish-brown, the pH of the water was 7.3, the odor was 4.6 points, suspended solids were 73.9mg/L, the light was 10 thousand lux, and the dissolved oxygen in the water was 3.3mg/L. It was found that the biochemical oxygen demand was high - 67.9mg O_2/L, the oxidation state was 41.9mg O_2/L, ammonia was 6.2mg/L, nitrites were 0.6mg/L, nitrates were 5.8mg/L, sulfates were 55.6mg/L, and chlorides were 48.7mg/L. A decrease in the amount of organo-mineral substances in the wastewater was observed when it was diluted in a ratio of 3:1 and 1:1.

Due to such plants growing naturally in biological ponds, the composition of wastewater is purified by 5-10% and transferred to other ponds. Suspended substances, i.e., colloid and dispersed substances, contained in the wastewater discharged into the first biological pond do not settle. Water purified from heavy metals is transferred to the second biological pond. Water samples were taken from the point of discharge of wastewater into the biological ponds and experiments were conducted in laboratory conditions.

Data Analysis

Calculation of Growth Rate

The rate of biomass increase was calculated using the following formula:

$$\text{Growth rate (g/day)} = \frac{M2-M1}{T2-T1}$$

Where:

- M_1 and M_2 are the initial and final biomass values,
- T_1 and T_2 are the corresponding time points in days.

A series of laboratory analyses were conducted using the following methodological approach: Preparation of experimental conditions. The experiments were conducted at the Environmental Pollution Monitoring Laboratory of the Samarkand Regional Department of Ecology and Environmental Protection. Azolla and Limna were grown separately in containers for each water option.

In this context, (g/d) stands for grams per day, which indicates the amount of a substance (such as feed or protein) provided to the sheep daily.

"crude protein/g/d in the form of duckweed" – here, /d also means per day, referring to the daily amount of crude protein provided (g/d).

RESULTS

It has been scientifically proven that *Azolla* and *Lemna* grow very quickly in domestic wastewater, producing from 100-150 to 500-623g of biomass/m^2 of water surface, and purifying various organo-mineral substances in water by 93-95%. As a result of growing *Lemna minor* L., it was found that the productivity of white Amur fish increased by 25-30% compared to the control group. As a result of the development of Azolla (*Azolla caroliniana* L.) and Little Duckweed (*Lemna minor* L.), the temperature was 20°C, and the light was 25 thousand lux. The pH of the water was 7.4, the suspended solids disappeared, the water became clear, and the smell disappeared. The dissolved oxygen content in the water was 7.5mg/L, the biochemical oxygen demand was 19.5mg O_2/L, the oxidation state was 23.2mg O_2/l, ammonia, nitrite, and nitrate were absorbed by the plant, sulfates were 38.3mg/L, and chlorides were 52.7mg/L. These indicators indicate the high potential of Azolla (*Azolla caroliniana* L.) and Lesser Duckweed (*Lemna minor* L.) in water purification (Table 1).

Table 1: Changes in water quality parameters during the experiment (when Azolla (*Azolla caroliniana* L.) and Lesser Duckweed (*Lemna minor* L.) were planted

Indicators	Initial state	10 days
Temperature (°C)	20.0	20.0
Light (lyuks)	25 000	25 000
pH	7.4	7.4
Suspended solids (mg/L)	Available	Not available
The color of the water	Brown	Clear
Smell	Brown	Clear
Dissolved oxygen (mg/L)	4.2	7.5
Biochemical oxygen demand, 5mg/L	38.3	19.5
Oxidation level (mg/O_2L)	45.1	23.2
Ammania (mg/L)	2.1	<0.5
Nitrites (mg/L)	1.3	<0.2
Nirates (mg/L)	4.8	1.1
Sulfates (mg/L)	52.4	38.3
Chlorides (mg/L)	65.7	52.7

Practical work was carried out in the biological treatment ponds of the Suvokava enterprise. 200g of Azolla (*Azolla caroliniana* L.) and Little Duckweed (*Lemna minor* L.) biomass were planted on 1m^2 of the pond's water surface. A total of 100kg of plant biomass was placed in a pond with a total area of 500m^{2,} and the experiment was observed for 10 days. As a result, plant biomass grew rapidly and water quality improved significantly. The plant biomass was delivered to the "Abduraxmon Chaykal baliqlari" fish farm in the Akdaryo district of the Samarkand region, and the fish were fed (Fig. 2). The next stage was aimed at determining the effect of feed on fish productivity. 2g/h ponds of the fishery were used. In the control pond, fish (carp, white carp, and grass carp) fed with traditional feeds (alfalfa, reed) were placed. In contrast, in the experimental pond, the same species of fish were fed with Azolla (*Azolla caroliniana* L.) and little duckweed (*Lemna minor* L.).

The experiment lasted from April to October 2024, and fish biomass was measured on scales monthly, and changes were recorded. The daily diet for grass carp (*Ctenopharyngodon idella* (Val.)) was determined based on the biomass of Azolla (*Azolla caroliniana* L.) and Lesser Duckweed (*Lemna minor* L.) at 2-15% of body weight and fed systematically. Final (October) measurements showed that the body mass of fish fed with *Azolla* and *Lemna* increased by 25-30% compared to fish fed with conventional feed. *Azolla caroliniana* L. and *Lemna minor* L. proved to be not only ecologically but also economically beneficial.

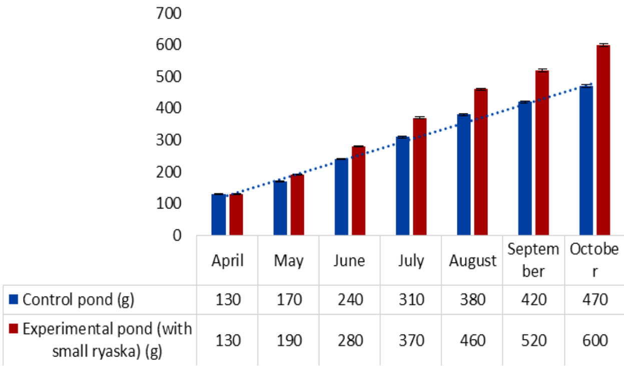

Fig. 2: Changes in body mass of white amur fish (April-October, 2024).

Fish products are essential in meeting the population's protein needs. Fish grown on fish farms and caught from natural reservoirs cannot fully meet the needs of the population of our republic. According to the recommendations of the Ministry of Health, each person should consume 30kg of fish products for healthy development. The majority of fish grown in our republic is grown in ponds.

According to the Ministry of Agriculture and Water Resources, the average productivity of fish farms in 2004 was 4 centners. The decrease in pond productivity is due, firstly, to the lack of mixed feed that fully satisfies the needs of fish, the low quality and high price of the produced feed, and secondly, to the lack of fish farming technology adapted to the conditions of a market economy. Based on farming technology, the most common fish for fish farming were carp, followed by crucian carp and white amur fish, which were stocked at a rate of 100-150/hectare to use the existing aquatic plants in the ponds.

In the era of a market economy, the high cost and low quality of compound feed, and the economic unprofitability of carp farming for fisheries, are leading to its abandonment. 90% of farmed fish are white carp, which are not popular among the population.

The potential of the white amur fish, which is popular among the population and can be sold on the market on a par with carp, is not yet fully utilized. Currently, one of the urgent problems in fisheries is the mixed cultivation of herbivorous fish in polyculture, the reproduction of the white amur (*Ctenopharyngodon idella* (Val.)) species, and the reproduction of this fish at the expense of higher aquatic plants in the fisheries of our republic. By densely keeping white amur fish in water bodies and feeding them at the expense of algae, it is possible to increase the productivity of water bodies and achieve additional economic efficiency. Amur whitefish begin to feed on aquatic plants when the water temperature is 10-12°C and the most favorable temperature for their development is 20-30°C.

The growth pattern of the fish depends mainly on the water temperature and food supply. Amur whitefish larvae begin to feed on aquatic plants within 30 days after reaching a length of 3cm (Fig. 3).

At low temperatures, fish selectively feed on aquatic plants, and when the water temperature rises from 18 to 30°C, their appetite increases and they consume more food. It is advisable to increase the density of white amur fish transferred to ponds and use *Azolla*, in addition to the existing underwater and aboveground plants in the pond.

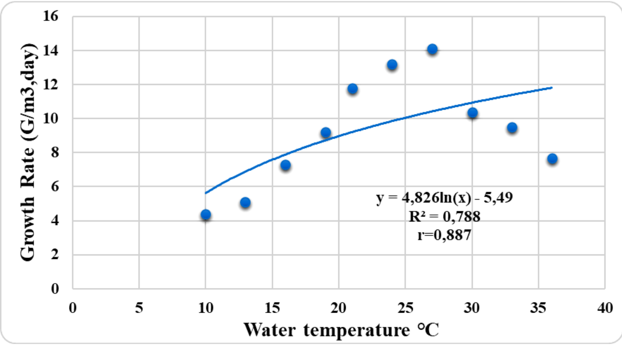

Fig. 3: Correlation relationship between water temperature and growth dynamics.

Alternative nutrients that can be used in feed preparation include *Lemna minor*. With a high nutritional content of 23.47% crude protein, 3.99% crude fat, 29.92% crude fiber, 23.6% ash and 19.02% nitrogen-free extract, *Lemna minor* L is the best choice as a feed. Its protein content is 13-16% higher than that of wheat and 19-20% higher than that of corn. White amur fish larvae begin to feed on *Lemna minor* L at an interval of 19 to 24 days (Fig. 4).

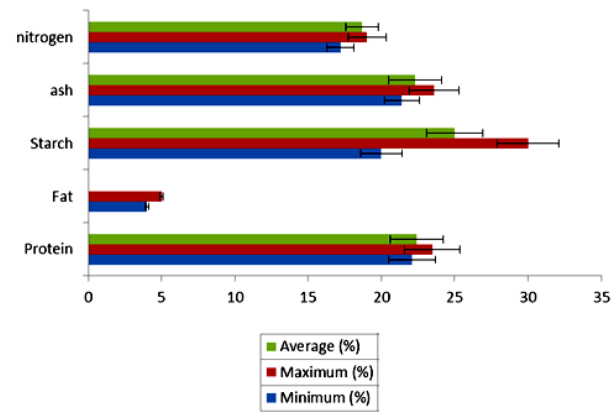

Fig. 4: Main nutrients (%) in dry matter content of *Limna minor* L.

This paper focuses on the trophic levels of two species of duckweeds (*Wolffia arrhizal* and *Lemna minor* L.). Using the development of optimal modeling of biological processes, we obtained recipes for individually balanced culture media for both species of *Lemnaceae* that allowed for a 3.0% higher total soluble protein yield from each population (Khvatkov et al., 2019). Taking into account certain technologies, based on production conditions and making some changes to them, the method of growing these plants in large water areas (0.6-1.1 ha) is being tested and introduced into production. To establish the widespread use of Azolla in various sectors of agriculture and to establish large-scale biomass production, it is necessary to create nutrient media that can be used as a nutrient in large reservoirs and water bodies, and to determine the effectiveness of these nutrient media in field conditions. It was planned to select a standard nutrient medium for control options. This was necessary to conduct field experiments uniformly, as the nutrient medium used for growing Azolla was crucial for keeping it in greenhouses in winter and outdoors in spring and summer.

Experiments were conducted in laboratory, open air and greenhouse conditions to study the effect of nutrient media prepared from various organic fertilizers on Azolla biomass yield and to determine how much biomass will be accumulated in the future in winter and summer in laboratory, greenhouse and open air conditions and how much biomass will be delivered to the consumer in each season. Data from the literature were used to determine the composition of the nutrient media used during the experiment. Several nutrient media have been used in the literature for the propagation of Azolla—composition of the first nutrient medium for the cultivation of Azolla (Table 2).

Table 2: Nutrient media for *Azolla caroliniana* (g/L)

№	Name of the nutrient medium	Shep manure (g/L)	Ferric chloride ($FeCl_3$,g/L)	Soil (g/L)
1	Olsen medium (original)	-	-	-
2	Original medium (prototype)	-	-	-
3	Experiment variant 1	500	3	2000
4	Experiment variant 2	1000	4	3000
5	Experiment variant 3	1500	5	4000
6	Experiment variant 4	2000	6	6000
7	Experiment variant 5	2500	7	8000
8	Experiment variant 6	3000	8	10000
9	Experiment variant 7	3500	9	12000

Nutrient medium (g/L)

1. Olsen medium (original),
2. Original medium (prototype),
3. Dung extract: 500g/L, ferric chloride: 3g/L, soil: 2000g/L
4. Dung extract: 1000g/L, ferric chloride: 4g/L, soil: 3000g/L
5. Dung extract: 1500g/L, ferric chloride: 5g/L, soil: 4000g/L
6. Dung extract: 2000g/L, ferric chloride: 6g/L, soil: 6000g/L
7. Dung extract: 2500g/L, ferric chloride: 7g/L, soil: 8000g/L
8. Dung extract: 3000g/L, ferric chloride: 8g/L, soil: 10000g/L
9. Dung extract: 3500g/L, ferric chloride: 9g/L, soil: 8000g/L

KCl	510	K_2NPO_4	102
$MgSO_4$	101	CaCl	118.5

Considering that the nutrient prepared from these salts is expensive for the mass propagation of Azolla, Nguyen Xiu Thuc (1988) used a convenient nutrient medium for his studies, the composition of which is as follows, mg/L:

KCl	504.8	K_2NPO_4	151.4
$MgSO_4$	70	CaCl	188.5

Azolla was grown in 4 tray-type devices (6m^2 long and 1m^2 wide) in the Fatima Kasimova massif of Samarkand district using a nutrient medium prepared from Azolla poultry manure (3g/L). The initial seedlings were planted on the water surface at a density of 400g/m^2. After nine days of cultivation, Azolla completely covered the surface of the 4 trays.

In order to study the effect of the selected nutrient medium and the nutrient medium prepared from 60 and 30% solutions of FBHMO (*Fertilizer bacterial-humic, mineral-organic*) fertilizer on biomass yield and to develop the overall growth of azolla, the following experimental scheme was conducted in 9 variants in 3 replicates for 15 days using the nutrient medium prepared from 60 and

30% solutions of FBHMO, concentrations of 0.1, 0.2, 0.3 and 0.4g/L, and RH (*remineralized humus*) (5g/L) for control, recommended by scientists of the Institute of Inorganic Chemistry of the Academy of Sciences of the Republic of Uzbekistan in 1998.

A. caroliniana (300g/m^2) + FBHMO (60%): 0.1g/L, 0.2g/L, 0.3g/L, 0.4g/L

A. caroliniana (300g/m^2) + FBHMO (30%): 0.1g/L, 0.2g/L, 0.3g/L, 0.4g/L

Control option *A. caroliniana* (300g/m^2) + RH (5g/L)

During the experiment, the daily growth of *A. caroliniana*, pH, room temperature, air temperature, nutrient medium temperature, and light environment were monitored (Table 3). In the nutrient medium prepared from a solution of 30% FBHMO 4.0g/L in water, the daily growth averaged 120±1.5g/m^2, in the solution with a concentration of 60% FBHMO (0.2g/L), the average was 117±1.1g/m^2, and in the control variant, the daily growth was 119±1.2g/m^2. In solutions with a concentration of 30% FBHMO (4.0g/L) and 60% FBHMO (2.0g/L), the biomass content was higher than in the other variants.

Table 3: *A. caroliniana* productivity in nutrient media prepared with different concentrations (g/L) of FBHMO (*Fertilizer bacterial-humic, mineral-organic*)

№	Amount of fertilizers (g/L)	Daily growth in 30% fertilizer (g/L)		Daily growth in 60% fertilizer (g/L_	
1	0.5	82.0±0.3	4.1±0.01	84.0±0.4	4.2±0.02
2	1.0	89.0±1.4	4.5±0.02	83.0±0.6	3.9±0.02
3	1.5	87.0±0.9	4.3±0.02	90.0±0.8	4.5±0.01
4	2.0	85.0±0.4	4.2±0.01	117±1.1	5.8±0.01
5	2.5	90.0±1.1	4.5±0.2	86.0±0.9	4.3±0.01
6	3.0	91.0±0.6	4.6±0.01	90.0±0.9	4.5±0.05
7	4.0	120±1.5	6.0±0.05	83.0±0.5	3.9±0.04
8	5.0	100±1.1	5.0±0.03	83.0±0.7	3.9±0.06
9	RH (5g/L)			119±1.2	6.0±0.03

RH - remineralized humus ($P<0.05$). The color of the biomass was dark red and green. which was different from that of biomass grown in a nutrient medium prepared with RH (5g/L). Experiments were conducted outdoors and in the laboratory in a warm room from December to February.

1 – variant *A. caroliniana* 300g/m^2 + 0.5g/L humus
2 – variant *A. caroliniana* 300g/m^2 + 1g/L humus
3 – variant *A. caroliniana* 300g/m^2 + 1.5g/L RH
4 – variant *A. caroliniana* 300g/m^2 + 2.0g/L RH
5 – variant *A. caroliniana* 300g/m^2 + FBHMO 30% at 2.5g/L
6 – variant *A. caroliniana* 300g/m^2 + FBHMO 60% at 3.0g/L
7 - variant *A. caroliniana* 300g/m^2 + FBHMO 30% at 4.0g/L
8 - variant *A. caroliniana* 300g/m^2 + FBHMO 30% at 5.0g/L
9 - variant *A. caroliniana* 300g/m^2 + Remineralized humus (RH) 5.0g/L

As can be seen from the results of the experiments. The highest biomass yield in laboratory conditions was obtained in a nutrient medium prepared from 3g/L of humus. With an average daily growth of 131.5±0.6g/m^2. In greenhouse and open-air conditions. The highest yield was obtained in a nutrient medium prepared from RH (5g/L). with an average daily growth of 116.4±0.7g/m^2 in the greenhouse and 130.1±0.5g/m^2 in the open air. As a result of the experiments. It was concluded that in all experiments conducted in the laboratory. It is advisable to use a nutrient medium prepared from humus (3g/L) with 30% FBHMO 4.0g/L and 60% FBHMO 2.0g/L solutions. Using these fertilizers in the laboratory is, firstly, inexpensive and, secondly, the amount of biomass obtained is high and is environmentally friendly compared to other nutrient media (Table 4).

The use of a nutrient medium prepared from RH (5g/L) in open air and greenhouse conditions gave good results. The daily growth rate was also higher in variants where biomass was harvested every 3-7 days. The use of this nutrient medium was determined to be one of the most effective methods for growing and multiplying biomass in the summer months and storing it in greenhouses in the winter months, and it is still used today.

Table 4: Biomass yield of *A. caroliniana* grown under different conditions

Food environments	Daily biomass/m^2		
Humus (1g/L)	79.8±0.4	79.1±0.4	78.7±0.5
Humuc (3g/L)	131.5±0.6	120.8±0.7	127.1±0.7
RH (3g/L)	79.3±0.3	95.5±0.5	96.2±0.6
RH (5g/L)	101.5±0.6	116.4±0.7	130.1±0.5
FBHMO 30% ni (4.0g/L)	111.5±0.5	114.6±0.6	126.9±0.7
FBHMO 60% ni (2.0g/L)	118.4±0.5	112.2±0.6	125.3±0.5

Note: RH - remineralized humus. FBHMO Fertilizer bacterial-humic. mineral-organic ($P<0.05$).

DISCUSSION

The paper highlights the potential of utilizing higher aquatic plants. Such as *Lemna minor* and *Water hyacinth*, as feed for herbivorous fish. Intensive cultivation of these plants can provide a sustainable and cost-effective feed source. Enhancing fish growth while reducing reliance on commercial feeds. The integration of these plants into fish farming not only ensures stable feed availability throughout the year but also contributes positively to environmental sustainability by improving water quality and minimizing negative ecological impacts (Pratiwy et al., 2024).

The paper does not specifically address the intensive cultivation of higher aquatic plants for feed preparation for herbivorous fish. It focuses on semi-intensive fish culture pond fertilization and the integration of tilapia with other farming systems (El-Sayed, 2020). The paper focuses on intensive fish culture systems primarily discussing complete feeds for carnivorous fish. It does not specifically address the intensive cultivation of higher aquatic plants for herbivorous fish feed preparation (*Complete Feeds—Intensive Systems*, 2022). The paper focuses on aquaponics. Integrating carp farming with lettuce cultivation. It examines the effects of different protein levels in fish feed on water parameters and plant growth. Highlighting improved biomass and root length with higher dietary protein for fish (Stoyanova et al., 2019). Intensive cultivation of higher aquatic plants. Such as Ipomoea aquatica and *Azolla pinnata* can enhance feed for herbivorous fish by providing high protein content and essential omega-3 fatty acids improving growth health and overall product quality in aquaculture (Omweno et al., 2024). The paper does not address the intensive cultivation of higher aquatic plants for herbivorous fish feed. Emphasizing its role in stimulating predatory behavior and enhancing nutrient assimilation in fish larvae (Luna-Figueroa, 2017). The paper focuses on the cultivation of the marine microalgae Tetraselmis striata for fish feed production. Emphasizing its high protein content and essential fatty acids. Which are crucial for aquaculture nutrition. Particularly for herbivorous fish (Patrinou et al., 2022). The paper does not specifically address the intensive cultivation of higher aquatic plants for herbivorous fish feed preparation. It focuses on fish feed strategies disease management and innovative substitutes in aquaculture rather than plant cultivation methods (Ejaz et al., 2024; Maldonado et al., 2024).

It focuses on the integration of aquaculture and hydroponics for producing animal forage, particularly using hydroponic corn in aquaponic systems (Borges et al., 2022).

Conclusion

Due to their biological characteristics. The Amur catfish (*Ctenopharyngodon idella*). Which feeds on aquatic plants plays an important role in the natural purification of water bodies and balancing the ecosystem. Their growth rate and level of nutrition depend mainly on the temperature of the water and the available food sources. According to the results of the study. Amur catfish begin to consume aquatic plants when the water temperature is 10–12°C. Moreover, the most active growth was observed in the range of 20–30°C. They consume food more actively, especially when the temperature rises above 18°C. When the larvae of white amur fish reach their typical length (3cm) in 18-30 days. They begin to feed on aquatic plants. In particular, *Limna minor* L and *Azolla caroliniana* Willd. The chemical composition of these plants has a high nutritional value. *Limna minor* L contains 30-32% protein. 20-30% starch and 4-5% fat. *Azolla caroliniana* Willd contains up to 20-30% protein up to 25-35% carbohydrates and is rich in biologically active substances. Studies show that these plants are not only economically cheap and easy to grow but also improve environmental sustainability and reduce production costs.

DECLARATIONS

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