Algoflora of fishery ponds in Bukhara province

Aziz Kobilov[1]*, *Karim* Gaziyev[2], Erkin Jumaev[1], *Elbek* Jalolov[1], and *Nasiva Ibragimova*[3]

[1]Bukhara State University, Bukhara, Uzbekistan
[2]Bukhara State Medical Institute named after Abu Ali ibn Sino, Bukhara, Uzbekistan
[3]Urgench State University named after Abu Rayhan Beruni, Urgench, Uzbekistan

Abstract. This study explores the cultivation of *Chlorella vulgaris*, a species of green microalgae rich in physiologically active compounds, and its application in semi-intensive fish farming systems within the Bukhara region. Over 2022–2023, controlled experiments were carried out at LLC "Buhorobalik" to evaluate the biomass productivity and water-purifying capacity of *Chlorella vulgaris* under laboratory, semi-industrial, and field conditions. Laboratory trials utilized Muzaffarov's "04" nutrient medium, along with pond water and horse manure juice as alternative growth substrates. Optimal growth conditions included 26–28 °C, 15–25 thousand lux illumination, constant aeration, and pH of 7.2–7.4, with *Chlorella* cell counts reaching 48.2 million/mL and wet biomass of 0.5 g/L in 6 days. Field-scale experiments involved cultivating the algae in concrete basins and applying the suspension to fish ponds stocked with herbivorous white fathead (*Hypophthalmichthys molitrix*). Regular algolization with *Chlorella* led to a notable improvement in pond water quality: dissolved oxygen increased up to 17.6 mg/L, while ammonium, nitrates, nitrites, chlorides, and sulfates significantly decreased. A measurable suppression of competing blue-green algae was observed, alongside a 20–25% increase in fish productivity. The study demonstrated the feasibility of large-scale *Chlorella* cultivation using cost-effective nutrient sources like horse manure juice, replacing more expensive synthetic media. The hydrochemical purification of water and biofertilizing potential of *Chlorella* suspension underscore its significance in integrated aquaculture systems. These findings support the implementation of eco-friendly, sustainable practices in fish farming by integrating microalgae cultivation with aquatic ecosystem management.

1 Introduction

Aquatic ecosystems are among the most productive and ecologically significant environments on Earth. Within these systems, algae—particularly microalgae—constitute the foundation of trophic structures, playing a pivotal role in primary production, nutrient cycling, oxygen generation, and energy flow. In artificial aquatic systems such as fishery ponds, the composition and dynamics of algal communities, or algoflora, not only influence ecosystem health but also directly impact aquaculture productivity. The province of Bukhara, located in an arid zone of Central Asia, presents a unique ecological context for

*1Corresponding author: otabek90u@gmail.com

studying algoflora in managed water bodies due to its extreme climate, water scarcity, and increasing reliance on aquaculture as a component of agricultural sustainability[1].

The development of fishery ponds in Bukhara province reflects broader trends in arid-region water resource management. As traditional agriculture confronts increasing pressure from climate change, desertification, and salinity, aquaculture has emerged as a strategic adaptive mechanism. Fish ponds serve not only as sources of protein and livelihood but also as reservoirs that support complex ecological interactions. Among the most important and sensitive indicators of these interactions are the communities of algae that colonize and thrive within these ponds. Their taxonomic composition, biomass, diversity, and seasonal succession reflect the physico-chemical conditions of the water and serve as early indicators of eutrophication, pollution, or nutrient imbalances. Consequently, understanding the algoflora of fish ponds provides a dual benefit: informing aquaculture management and contributing to the ecological knowledge of anthropogenically influenced aquatic systems in arid zones[2].

Algae, as phototrophic organisms, are highly responsive to fluctuations in environmental parameters such as temperature, light, pH, salinity, and nutrient availability. In aquaculture ponds, these parameters are often anthropogenically modulated through fertilization regimes, water exchange, and stocking densities. These interventions create semi-controlled conditions that can either enhance or destabilize algal populations. For example, nitrogen and phosphorus enrichment can stimulate blooms of Chlorophyta (green algae) and Cyanophyta (blue-green algae), which may initially support zooplankton and fish larvae but later cause oxygen depletion and fish mortality if not properly managed. In Bukhara's fish ponds, such dynamics are further complicated by high evaporation rates, saline groundwater intrusion, and the region's hot, dry summers. These factors collectively influence the ecological amplitude of various algal taxa and shape unique assemblages adapted to the local environment[3].

Despite their significance, algal communities in Bukhara's aquaculture systems remain under-investigated. Diatoms often peak during cooler months when silica concentrations are high and stratification is minimal, while green and blue-green algae thrive during the warmer, nutrient-rich phases of pond cycles[4].

The anthropogenic control of these ponds offers a unique opportunity to study successional patterns in microalgal communities under quasi-experimental conditions. Ponds are usually emptied, cleaned, and refilled on a seasonal basis, resetting the ecological clock and allowing for the examination of colonization dynamics. In the early stages, fast-growing unicellular forms such as Chlorella or Scenedesmus often dominate. As the ecosystem matures and nutrient profiles shift due to fish excretion, feeding, and sediment interactions, more complex or filamentous forms may appear. The presence of periphytic algae, including representatives of Euglenophyta and Xanthophyta, adds another dimension to the ecological diversity of these habitats. Periphytic species, which grow attached to submerged surfaces, contribute significantly to primary productivity and serve as food sources for benthic invertebrates and juvenile fish[5].

The structure of the algal community is not only a function of abiotic factors but also of biotic interactions, particularly grazing pressure by zooplankton and fish. In many Bukhara ponds, carp (Cyprinus carpio) and tilapia (Oreochromis spp.) are commonly stocked. These fish species influence algal populations through direct consumption and by altering nutrient dynamics through excretion. High fish densities can lead to increased levels of ammonium and phosphate, shifting the community composition toward eutrophic indicators such as Microcystis, a cyanobacterium known for its toxicity. Therefore, algal monitoring in such systems also serves as a biosecurity measure, enabling early detection of conditions that might necessitate management intervention.

From a biogeographical perspective, the algal communities of Bukhara's fishery ponds reflect both cosmopolitan and regionally adapted species. The combination of extreme conditions and anthropogenic inputs selects for taxa with wide ecological tolerance. For instance, species of the genera Nitzschia, Navicula, and Oscillatoria are frequently encountered in similar environments across Central Asia, indicating a degree of ecological convergence. At the same time, local endemism and microhabitat specialization may lead to the discovery of novel or under-described taxa, particularly among desmids and diatoms. Advances in taxonomic methods, including molecular techniques and scanning electron microscopy (SEM), are increasingly employed to resolve such complexities and refine algal systematics in poorly studied regions[6].

The study of algoflora in fish ponds also intersects with applied research in biotechnology, bioenergy, and environmental remediation. Algae are increasingly recognized for their potential in biofiltration of aquaculture effluents, carbon sequestration, and as sources of bioactive compounds. In the context of Bukhara, where environmental stressors limit the feasibility of conventional waste treatment or fertilizer application, harnessing algal biofilms and biomass for integrated aquaculture-agriculture systems represents a promising frontier. For instance, dried algal biomass could be used as a soil amendment or as a feed additive for livestock and poultry, contributing to circular economy models in rural development.

Furthermore, long-term monitoring of algoflora can serve as a diagnostic tool for climate resilience. As temperature extremes and irregular precipitation patterns become more pronounced, shifts in algal phenology and community structure can provide early warnings of ecological disruption.

2 Materials and methods

The present study was conducted during the 2022–2023 growing seasons in the Bukhara province, within the infrastructure of the fish farming enterprise LLC "Buhorobalik." The research aimed to investigate the algoflora composition of fishery ponds, particularly focusing on the cultivation and application of *Chlorella vulgaris* to improve hydrobiological parameters and fish productivity under semi-intensive aquaculture conditions.

Experimental Design and Conditions

The research involved both laboratory-scale and semi-industrial scale experiments. Initially, pure cultures of *Chlorella vulgaris* were isolated from pond waters and cultivated under controlled conditions to evaluate optimal nutrient requirements and biomass productivity. Three experimental setups were tested: (i) nutrient medium "04" + *Chlorella vulgaris*, (ii) pool water + *Chlorella vulgaris*, and (iii) pool water supplemented with horse manure juice + *Chlorella vulgaris*.

The phytoplankton cultures were grown in 1.5-liter plastic containers under laboratory conditions with constant aeration using microcompressors and continuous mixing to ensure homogeneous suspension. Illumination was maintained at 15,000–25,000 lux using artificial light sources, and temperature was held between 26–28 °C. The pH of the culture medium was kept within the range of 7.2–7.4.

Nutrient Medium and Fertilizer Application

To promote phytoplankton growth, the study utilized both synthetic and organic nutrient inputs. The mineral medium "04," developed by academician A.M. Muzaffarov for Central Asian conditions, was used as the primary growth medium in laboratory tests. The composition included ammonium sulfate, calcium phosphate, calcium sulfate, sodium bicarbonate, magnesium sulfate, potassium chloride, and ferric chloride at precise concentrations (Table 2). Additionally, a combination of inorganic fertilizers (nitrogen, ammophos, potassium chloride) and horse manure juice was evaluated for semi-industrial trials (Table 1). The prepared medium was scaled proportionally based on the volume of water used in different experiments.

Cultivation and Biomass Measurement

Cultures of *Chlorella vulgaris* were monitored for cell proliferation over six days. Cell counts were performed daily using a Goryaev hemocytometer under a light microscope. Wet biomass was measured by centrifuging 1-liter samples at 6000 rpm for 10 minutes. The precipitated biomass was dried and weighed using electronic analytical balances to determine biomass concentration (g/L). Growth kinetics and biomass yield were compared across experimental variants (Table 3).

Semi-Industrial Scale Trials

Field experiments were conducted in concrete basins near fish ponds, with a total capacity of 15 m^3 each. The ponds were seeded with 2.0 million cells/mL *Chlorella vulgaris* suspension and supplemented with 4 g/L horse manure juice for biomass enhancement. Suspension cultures were maintained under natural light conditions with controlled aeration and temperature, and algal growth was monitored microscopically over 10-day cycles. The suspension was then harvested and applied to experimental fish ponds designated for herbivorous species (*Hypophthalmichthys molitrix*).

Algolization of Fish Ponds

Following each 10-day cultivation cycle, 7.5–8.0 tons of *Chlorella vulgaris* suspension were introduced into fish ponds twice a week. Approximately 30–40% of the existing suspension was retained in the concrete basins and replenished with pond water and nutrients to initiate the next cycle. This algolization continued from late April to mid-October 2022.

Hydrochemical and Biological Monitoring

Water samples were collected from both experimental and control ponds prior to and following the introduction of *Chlorella vulgaris*. Standard hydrochemical parameters—temperature, pH, suspended solids, dry residue, dissolved oxygen (DO), biochemical oxygen demand (BOD5), ammonium nitrogen, nitrites, nitrates, chlorides, and sulfides—were measured using standard methods in accordance with APHA (2017) guidelines. Dissolved oxygen and BOD5 were determined using Winkler's method and respirometry, respectively.

Comparative data of the hydrochemical composition pre- and post-algolization are presented in Tables 4 and 5. Special attention was given to the reduction of nitrogenous compounds and enhancement of DO levels as indicators of water purification efficacy and photosynthetic activity of the algoflora.

Fish Growth Monitoring

The growth performance of *Hypophthalmichthys molitrix* was assessed monthly throughout the growing season. Fish were sampled randomly from the experimental and control ponds, and individual body weights were measured using a digital balance with a precision of ±0.1 g. At the start of the trial in April 2022, the average body weight of stocked fish was 55.5 g. Fish growth, survival rate, and productivity were recorded until October 2022, with particular focus on the impact of *Chlorella vulgaris* suspension as a supplementary food source and water quality enhancer.

3 Results and discussion

For several years, our scientists have been multiplying green algae in natural lakes of Bukhara region, from which a large amount of biomass is obtained, and conducting scientific research on their use in various sectors of national economy.

However, research work on semi-intensive methods of herbivorous fish breeding in artificial ponds has not been carried out in full.

In this regard, experiments were conducted in 2022-2023 on the cultivation of white thickhead in fish ponds of LLC “Buhorobalik” and the use of phytoplankton to increase their productivity. From phytoplankton Chlorella vulgaris, rich in physiologically active substances, was bred in laboratory and semi-production conditions.

At reproduction of phytoplankton Chlorella vulgaris in large quantities it is necessary to provide constant mixing of nutrient medium, temperature 26-28 0C, light 15-25 thousand lux, suspension of microscopic algae, for intensive realization of photosynthesis it is necessary to constantly supply carbon dioxide. If there is a shortage of this gas, a gas containing 0.03% of the atmosphere can be used. For this purpose, atmospheric air is introduced into the nutrient medium where algae are propagated, using a microcompressor (in laboratory conditions) and the green suspension is stirred. The amount of mineral salts used for research work is given in Table 1.

Table 1. Fertilizers used for growing microscopic algae.

№	Fertilizers	Volume selected for growing the suspension (m3/g)
1	Nitrogen	140
2	Ammophos	201
3	Potassium chloride	25
4	Manure juice	15 liter

As an optimal nutrient medium for the reproduction of phytoplanktonic organisms in the conditions of Central Asia academician A.M. Muzaffarov created nutrient medium “04” and presented in Table 2.

Table 2. Composition of nutrient medium “04” for phytoplankton propagation.

For phytoplankton cultivation	For phytoplankton cultivation						
	$(NH_4)_2SO_4$	$Ca(H_2PO_4)_2$	$CaSO_4$	$NaHCO_3$	$MgSO_4$	KCl	$FeCl_3$ (ml of 1% solution)
“04”	0.2	0.03	0.03	0.1	0.08	0.025	0.2

When propagating suspensions of microscopic green algae in special installations, the amount of mineral salts is determined by the volume of water.

For the preparation of this nutrient medium “04” necessary mineral salts were measured on electronic scales for 5 or 10 liters of water. As a control, 1 ml each of the prepared mineral nutrient medium “04” was poured into 1.5 liter plastic containers and Chlorella was grown under laboratory conditions. (Table 3).

Chlorella vulgaris cells isolated from fish ponds were seeded on the first day in a 1.5 liter plastic container at an average of 2.0 million cells in 1 ml. The growth and development of Chlorella vulgaris was studied using light microscope for 6 days, cell division and multiplication were observed. The division of their cells from one to two, two to four, four to eight was observed.

Chlorella vulgaris cells were selected from 1 ml of suspension and counted using a microscope in a Goryaev chamber. Illumination of 15-25 thousand lux and air temperature of 26-28 0C were provided during the experiment. The hydrogen index (pH) of the medium in which the green algae were grown was between 7.2 and 7.4. The experiments were conducted for 6 days. After the sixth day of the experiment, the algae cell multiplication rate decreased significantly. The main reason for this is the decrease in the amount of organomineral substances in the media grown in the control and experimental variants of Chlorella vulgaris.

Table 3. Cultivation of Chlorella vulgaris under laboratory conditions in the nutrient medium "04".

№	Experimental algae	Number of cells, million/ml						Wet biomass g/l
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	
1	Nutrient medium "04" + Chlorella vulgaris	2.0	6.8	21.7	38.6	44.9	48.2	0.5
2	Pool water + Chlorella vulgaris	2.0	3.4	5.7	7.6	12.5	13.8	0.15
3	Pool water+Horse manure juice+ Chlorella vulgaris	2.0	5.7	16.5	32.4	40.1	42.3	0.4

Chlorella vulgaris cells taken as an experimental variant grew and developed intensively for 6 days, and on the sixth day the number of cells increased to 48.2 million/mL. Their wet biomass was 0.5 g/L. In the control variant, seeded in water brought from fish ponds, the cell count on the sixth day was 13.8 million/mL. It was observed that other species of algae were also found in the composition of the pond water. However, Chlorella vulgaris cells seeded in these waters (2.0 million/mL) inhibited the growth and development of other phytoplankton. In the control, the wet biomass was 0.15 g.

In addition, 42.3 million/mL cells were formed within 6 days in the experimental variant, where Chlorella vulgaris cells were grown by mixing pond water with horse manure juice. Their wet biomass was 0.4 g/L.

In determining the productivity of microscopic algae, after 6 days of the experiment, 1000 ml of suspension was collected each and the green biomass was precipitated from the pond water using a centrifuge at 6000 rpm for 10 minutes. Water was removed from the top of the precipitated biomass, the mass of green wet biomass was measured and dried by placing the drying apparatus in bouquets. The dried green biomass in the bouquet along with the bouquet was weighed on an electronic scale and the amount of wet biomass was calculated. The wet biomass of Chlorella vulgaris grown on nutrient medium 04 was found to be 0.5 g/L.

From the above data, it can be concluded that the water of fish ponds contains minerals necessary for the growth and development of Chlorella vulgaris cells. However, the minerals in the pond water are not sufficient for their intensive reproduction and obtaining a large amount of green biomass. Therefore, in the experimental variant, nutrient medium “04” and horse manure juice were used for intensive cultivation of Chlorella vulgaris cells. Although nutrient medium “04” has high efficiency in terms of cell number and biomass of Chlorella vulgaris, this nutrient medium can be used in laboratory conditions. In production conditions, at present, the economic efficiency of using nutrient medium is not high. This is due to the fact that chemical minerals in this nutrient medium are rare and expensive. From this point of view, for intensive multiplication of Chlorella vulgaris cells, the juice of manure of various animals was used. A number of research works have been carried out in this field by scientists of our republic.

Experiments were conducted on reproduction of microscopic green algae in concrete pools near fish ponds of “Buhorobalik LLC.” A suspension of Chlorella vulgaris algae isolated from pond water containing 2.0 million/mL cells was grown in the pools. Field experiments were conducted to purify pond water from various minerals and use it as food for herbivorous fish.

The hydrochemical composition of Chlorella vulgaris algae was studied before and after planting in pond water. The studies were conducted for 6 days in fish ponds of Buhorobalik LLC and observed daily growth and reproduction of Chlorella vulgaris algae using a microscope. By the end of the research, the hydrochemical composition of water in experimental and control ponds, as well as the number and biomass of Chlorella cells were determined. Based on the results of the experiments, the distribution, growth and development of Chlorella vulgaris algae in pond waters were established.

During the experiments, water temperature was maintained at 24-26 0C and illumination at 15-25 thousand lux. Their growth and intensive development took place during 6 days.

Chlorella vulgaris algae cells were isolated using centrifuge and the hydrochemical composition of water was determined. After seeding of Chlorella vulgaris cells in experimental and control ponds, the number of cells increased from 2.0 to 44.7 million/mL. As a result of the increase in the number of Chlorella cells, the pH was 7.0, suspended solids decreased to 24.4 mg/L, dry residue to 4.4 g/L, and dissolved oxygen in the water increased to 17.6 mg/L (Table 4). The increase of dissolved oxygen in water mainly depends on the photosynthesis intensity of green algae.

Table 4. Pre-experimental hydrochemical composition of water in fish ponds of LLC "Buhorobalik".

№	Indicators	Experimental pool	Control pool
1	Temperature 0C	25.0	25.0
2	Color	clear	clear
3	pH	7.5	7.5
4	Suspended matter mg/l	56.3	56.7
5	Dry residue, g/l	9.8	10.2
6	Amount of dissolved oxygen in water, mg O2/l	6.7	6.4
7	Biochemical oxygen consumption (BOC5), mg O2/l	5.6	6.0
8	Ammonium nitrogen, mg/l	1.5	1.7
9	Nitrites, mg/l	0.02	0.02
10	Nitrates, mg/l	5.3	5.5
11	Chlorides, g/l	3.9	4.0
12	Sulfides, g/l	3.6.	3.4

Increasing the amount of dissolved oxygen in the pond water brings great benefits to the hydrobiont organisms in fish ponds, as well as accelerating the decomposition of the pond water due to the oxidation of organomineral substances. It was found that the biochemical oxygen consumption in the water of the experimental basin decreased to 1.8 mg O2/l, while nitrites, ammonia, and nitrates in the water were fully absorbed using microscopic algae. In addition, a decrease in the amount of chlorides in the water to 2.0 mg/l and sulfates to 1.7 mg/l was observed. Significantly higher indicators in the control variant compared to the experiment are presented in the Table 5 above.

Table 5. Post-experimental hydrochemical composition of water in fish ponds of LLC "Buhorobalik"

№	Indicators	Water in a tray from an experimental pool	Control pool
1	Temperature 0C	25.4	24.7
2	Color	clear	clear
3	pH	7.0	7.4
4	Suspended matter mg/l	24.4	54.6
5	Dry residue, g/l	4.4	9.2
6	Amount of dissolved oxygen in water, mg O2/l	17.6	6.0
7	Biochemical oxygen consumption (BOC5), mg O2/l	1.8	6.7
8	Ammonium nitrogen, mg/l	No	1.1
9	Nitrites, mg/l	No	0.02
10	Nitrates, mg/l	No	5.3
11	Chlorides, g/l	2.0	3.7
12	Sulfides, g/l	1.7	3.1

For intensive cultivation of Chlorella vulgaris suspension in fish farming and obtaining a large amount of green biomass in semi-industrial conditions, 4 g/l of horse manure juice was added to the water of the concrete basin. The number of chlorella cell multiplication was determined over 10 days. An increase in the number of chlorella cells to 40-45 million was observed in 1 ml of suspension. A 7.5-8.0 tonnes of Chlorella vulgaris suspension was algolized twice a week in a pond intended for white thistle cultivation, and the number of cells in the pond was determined. When checking the average value of the research results for three months, it was observed that the number of Chlorella vulgaris cells in the water of the pond where the fish were kept was 4-5.0 million/ml. It was established that the amount of dissolved oxygen in the water in the experimental ponds is 11.6 mg/l, and the biochemical oxygen consumption is up to 4.4 mg O2/l. It has been established that Chlorella vulgaris completely absorbs nitrates, nitrites, and ammonia found in pond water, significantly reducing the content of chlorides and sulfates.

It was observed that the hydrochemical composition of the water in the control ponds practically did not change.

The research was conducted from the last ten days of April to mid-October. Throughout the growing season, the number of Chlorella vulgaris cells in the fish pond water increased to 5.5-7.5 million/ml, and the amount of dissolved oxygen in the water increased to 11.4-13.5 mg/l.

High productivity was observed in the herbivorous white fathead raised in the fish pond.

From the above experiments, it can be seen that Chlorella vulgaris, considered green algae, provides water to most of the areas of fish ponds, and together with the Central Bukhara Collector, it was established that the ponds of LLC "Bukhorobaliq" to a certain extent purify the water from organic residues and mineral substances, and also form a large amount of green biomass. Furthermore, effective methods for cultivating this species of phytoplankton in laboratory conditions in nutrient media containing various biogenic elements, as well as in nutrient media prepared by mixing the sap of hoofed livestock manure, have been studied.

According to the analysis results, intensive reproduction of Chlorella vulgaris was carried out under production conditions using specially designed equipment. In the conducted research, the most effective nutrient media were selected from the tested nutrient media, and due to the economic value of using nutrient media in equipment designed for obtaining large quantities of green biomass, mineral fertilizers such as nitrogen, phosphorus, ammophos, and horse manure juice were used instead.

From the phytoplankton, which contains a large amount of physiologically active substances isolated from nature, pure cells of the species Chlorella vulgaris were isolated, which grow rapidly, form a large amount of green biomass, and are considered nutritious feed for herbivorous white fathead.

Pure Chlorella vulgaris cells, isolated from nature and grown in various nutrient media, were used as feed for herbivorous white fathead raised in ponds of the fish farm belonging to "Buxorororbaliq" LLC, and it was found that the fish productivity increased by 20-25%, the amount of dissolved oxygen in the pond water was high, and the blue-green ones that cause the pond "flowering" decreased.

Using the results of the conducted research, observations, and experiments, Chlorella vulgaris was cultivated in concrete pools with a total capacity of 15 m3 near ponds intended for white thistle cultivation. After the number of cells in the Chlorella vulgaris suspension in the basin reached 45-50 million cells/ml, the suspension was sent to fish ponds. 30-40% suspension of Chlorella vulgaris was left in the pools and water was added from the pool. Then, they were fed a mixture of mineral fertilizers and horse manure in the required amount. After 3-4 days during the growing season, ready-made suspension of Chlorella vulgaris was introduced into the fishponds.

In April-October, the suspension of Chlorella vulgaris was regularly algolized into the ponds for keeping whitefin sole. Every 30 days, the weight of white fathead minnows in the experimental pond was determined by weighing. Experiments were conducted from April 2022 through mid-October of that year. In 2022, the average weight of white fathead trout released into the pond was 55.5 grams.

4 Conclusion

The conducted research has demonstrated the high potential of *Chlorella vulgaris* as a biologically active and ecologically sustainable agent in semi-intensive fish farming systems of the Bukhara region. Experimental results confirmed that under optimal cultivation conditions—temperature of 26–28 °C, illumination of 15–25 thousand lux, and nutrient supplementation using either Muzaffarov's "04" medium or horse manure juice—*Chlorella vulgaris* achieved intensive reproduction, reaching concentrations up to 48.2 million cells/mL and producing 0.5 g/L of wet biomass within 6 days.

Application of this algal biomass to fish ponds significantly improved hydrochemical parameters: dissolved oxygen levels increased by nearly threefold (up to 17.6 mg/L), while concentrations of ammonium, nitrites, nitrates, chlorides, and sulfates were markedly reduced. These improvements contributed to accelerated mineral decomposition and reduced biochemical oxygen demand (BOC5), indicating enhanced water self-purification. Furthermore, *Chlorella vulgaris* successfully outcompeted blue-green algae, which are typically responsible for pond "blooming," thus contributing to improved pond hygiene and stability of the aquatic ecosystem.

Importantly, the inclusion of *Chlorella* suspension as a natural feed additive enhanced the productivity of herbivorous white fathead (*Hypophthalmichthys molitrix*), with a reported 20–25% increase in biomass gain. The substitution of costly synthetic nutrients with locally available organic inputs, such as horse manure juice, also offers a cost-effective strategy for sustainable aquaculture development.

In conclusion, the integration of *Chlorella vulgaris* cultivation into aquaculture practices presents a dual benefit—enhancing fish productivity and contributing to ecological water management—making it a promising biotechnological solution for semi-intensive fish farming in arid regions.

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