Research Article

Effects Of Biofloc Technology On Fish Growth And Water Quality

Sahreen Naseer[1], Kashish Sharma[2], Satnam Singh[3] Monika Devi[4], Dr. Arshpreet Kaur[5], Uzma Roheen[6], Vanshika Tyagi Gupta[7], Shivani[8]

[1]Assistant Professor in Zoology, University School of Life Sciences, Rayat Bahra University Mohali. Email: Sahreen.18668@rayatbahrauniversity.edu.in, Orchid id: 0009-0007-6342-4010.
[2]Assistant Professor in Biotechnology, University School of Life Sciences, Rayat Bahra University Mohali. Email: kashish.19786@rayatbahrauniversity.edu.in, Orchid id: 0000-0002-7918-3457.
[3]Assistant Professor in Biotechnology, University School of Life Sciences, Rayat Bahra University Mohali. Email: Satnam.18789@rayatbahrauniversity.edu.in, Orchid id: 0009-0008-3742-2318
[4]Teaching Assistant, University School of Life Sciences, Rayat Bahra University Mohali. Email: monika.20382@rayatbahrauniversity.edu.in, Orchid id -0009-0003-7714-896X.
[5]Assistant Professor, University School of Life Sciences, Rayat Bahra University Mohali. Email: arshpreet.20529@rayatbahrauniversity.edu.in, Orchid id-0009-0008-3742-2318.
[6] University School of Life Sciences, Rayat Bahra University Mohali. Email- uzmaroheenkhan121@gmail.com, Orchid id-0009-0001-9016-6789.
[7]Assistant professor, Rayat Bahra University. Email: Drvanshikatyagigupta@gmail.com, Orchid id:0008-0005-0481-6781.
[8]PhD scholar, Rayat Bahra University Mohali. Email. shivaniheer8427@gmail.com, Orchid id 0009-0007-1151-0486.

Abstract

Biofloc Technology has emerged as one of the most promising sustainable aquaculture systems for enhancing fish production while maintaining optimal water quality through efficient microbial nutrient recycling. The technology is based on the manipulation of the carbon-to-nitrogen ratio, which promotes the proliferation of heterotrophic microorganisms capable of converting toxic nitrogenous wastes into protein-rich microbial biomass known as bioflocs. These bioflocs function both as biological filters and as a natural supplementary feed containing proteins, essential amino acids, lipids, vitamins, minerals, digestive enzymes, probiotics, and bioactive compounds. This review critically evaluates the effects of Biofloc Technology on fish growth performance and water quality by synthesizing findings from published scientific literature. The reviewed evidence demonstrates that BFT significantly improves final body weight, weight gain, specific growth rate (SGR), feed conversion ratio, protein utilization, digestive enzyme activity, immune response, disease resistance, and survival rate in several commercially important aquatic species, including Nile tilapia, common carp, African catfish, Pacific white shrimp, and freshwater prawns. Furthermore, Biofloc Technology effectively enhances water quality by reducing ammonia, nitrite, and organic waste accumulation while maintaining stable pH, dissolved oxygen, alkalinity, and microbial balance through continuous nutrient recycling. The system also minimizes water exchange requirements, conserves freshwater resources, decreases nutrient-rich effluent discharge, lowers feed costs, and reduces the environmental impact of intensive aquaculture. Despite its considerable biological, environmental, and economic advantages, successful implementation of BFT requires continuous aeration, careful management of the carbon-to-nitrogen ratio, regular monitoring of water quality, and technical expertise. Future research should focus on microbial community optimization, cost-effective carbon sources, artificial intelligence (AI)-based water quality monitoring, integration with recirculating aquaculture systems and aquaponics, and long-term commercial-scale evaluation to improve production efficiency and sustainability. Overall, the available scientific evidence indicates that Biofloc Technology represents an environmentally sustainable, economically viable, and highly effective aquaculture production system capable of improving fish growth performance, maintaining superior water quality, and supporting global food security.

Keywords: Biofloc Technology (BFT), Aquaculture, Fish Growth Performance, Water Quality, Feed Conversion Ratio (FCR), Specific Growth Rate (SGR), Carbon-to-Nitrogen Ratio, Microbial Biomass, Sustainable Aquaculture, Nitrogen Recycling,

INTRODUCTION

Biofloc Technology is an advanced and environmentally sustainable aquaculture practice that improves fish production while maintaining superior water quality through the manipulation of microbial communities. Unlike conventional aquaculture systems, which require frequent water exchange to control the accumulation of toxic nitrogenous wastes, BFT operates on the principle of nutrient recycling. Organic wastes, uneaten feed, and fish excreta are converted into microbial biomass by beneficial heterotrophic bacteria through the addition of an external carbon source. This microbial biomass, known as biofloc, serves not only as a natural biofilter but also as a valuable supplemental feed rich in proteins, lipids, vitamins, minerals, digestive enzymes, and beneficial microorganisms.[1](Liu, et al 2025) Consequently, BFT reduces feed costs, conserves water, minimizes environmental pollution, and improves the overall productivity and sustainability of aquaculture systems. The technology has been successfully applied to the culture of several commercially important species, including Nile tilapia Pacific white shrimp common carp African catfish and freshwater prawns. As concerns about water scarcity, environmental degradation, and food security continue to grow, Biofloc Technology has emerged as one of the most promising innovations for intensive and eco-friendly aquaculture.[2] (Dheeran, et al 2025) One of the major challenges in intensive aquaculture is the accumulation of toxic nitrogenous compounds such as ammonia (NH_3/NH_4^+) and nitrite (NO_2^-), which are generated from fish excretion, uneaten feed, and decomposition of organic matter. Elevated concentrations of these compounds impair fish growth, damage gill tissues, suppress immune function, reduce feed intake, and may ultimately lead to mass mortality. Traditionally, fish farmers have relied on frequent water exchange to maintain acceptable water quality. However, this practice requires enormous quantities of freshwater, increases production costs, and results in the discharge of nutrient-rich effluents into natural water bodies, contributing to eutrophication and environmental pollution.[3](Shahadat Hossain, et al 2025) Therefore, sustainable alternatives capable of maintaining water quality with minimal water exchange have become essential for modern aquaculture. Biofloc Technology has emerged as one of the most innovative and environmentally sustainable approaches to intensive aquaculture. Originally proposed by Avnimelech in the 1990s, the technology utilizes naturally occurring microorganisms to recycle nutrients within the culture system. Instead of allowing nitrogenous wastes to accumulate, heterotrophic bacteria rapidly assimilate dissolved ammonia into microbial biomass after the addition of an external carbon source. This process is achieved by maintaining an appropriate carbon-to-nitrogen ratio, generally between 15:1 and 20:1, which promotes rapid bacterial growth and efficient nutrient recycling. The resulting microbial aggregates, commonly known as bioflocs, consist of bacteria, algae, fungi, protozoa, rotifers, organic particles, extracellular polymeric substances (EPS), and mineral components.[4] (Raza, et al 2024) Bioflocs serve two important functions within the aquaculture environment. First, they function as biological filters by removing toxic nitrogenous wastes from the water through microbial assimilation, thereby maintaining superior water quality. Second, they act as a highly nutritious natural food source for cultured fish and shrimp. Biofloc biomass is rich in crude protein, essential amino acids, fatty acids, vitamins, minerals, digestive enzymes, probiotics, and immunostimulatory compounds. Fish continuously graze on these suspended microbial particles throughout the culture period, improving nutrient intake, feed utilization, digestive efficiency, and growth performance while simultaneously reducing dependence on commercial feed. Since feed accounts for nearly 50–70% of total aquaculture production costs, the supplemental nutrition provided by bioflocs significantly improves economic efficiency. Beyond improving fish nutrition, Biofloc Technology contributes substantially to fish health and disease resistance. The microbial communities present within bioflocs establish a balanced aquatic ecosystem by competing with pathogenic microorganisms for nutrients and attachment sites.[5] (Minaz, et al 2025) Beneficial bacteria produce antimicrobial substances and probiotic metabolites that suppress disease-causing organisms, while microbial cell wall components such as β-glucans, peptidoglycans, nucleotides, and polysaccharides stimulate the innate immune system of cultured fish. Consequently, fish reared in biofloc systems generally exhibit stronger immune responses, lower disease incidence, reduced antibiotic requirements, and higher survival rates than those cultured under conventional farming conditions. Another remarkable advantage of Biofloc Technology is its positive impact on environmental sustainability. Unlike traditional pond culture, where large volumes of water are discharged regularly, BFT systems operate with minimal or nearly zero water exchange. Continuous microbial recycling converts organic wastes into useful biomass rather than allowing sludge accumulation on the pond bottom. This significantly reduces freshwater consumption, minimizes nutrient discharge into surrounding ecosystems, lowers greenhouse gas emissions associated with waste decomposition, and decreases the ecological footprint of aquaculture operations. Therefore, Biofloc Technology aligns closely with the principles of sustainable aquaculture and supports the United Nations Sustainable Development Goals (SDGs), particularly those related to food security, clean water, responsible production, and aquatic ecosystem conservation.[6](Ahmad, et al 2024)

EFFECTS OF BIOFLOC TECHNOLOGY ON FISH GROWTH

1. Enhancement of Growth Performance

One of the most significant advantages of Biofloc Technology is its ability to enhance the growth performance of cultured fish. Growth is influenced by the availability of nutrients, feed efficiency, environmental conditions, and the physiological health of the fish. In biofloc systems, microorganisms continuously convert nitrogenous wastes into microbial protein, creating a natural food source that complements formulated feeds. The biofloc particles contain proteins, essential amino acids, lipids, carbohydrates, vitamins, minerals, and bioactive compounds that are readily consumed by fish throughout the culture period. This continuous access to high-quality natural feed improves nutrient intake and reduces nutritional deficiencies. Additionally, the microbial enzymes present in bioflocs enhance digestion and nutrient absorption, allowing fish to utilize dietary nutrients more efficiently. Numerous studies have reported significantly higher final body weight, greater weight gain, improved specific growth rate (SGR), and increased biomass production in fish cultured under biofloc conditions compared with conventional systems. Improved growth has been documented in species such as Nile tilapia, common carp, African catfish, and various shrimp species, making BFT an effective strategy for maximizing aquaculture productivity.[2](Liu, et al 2025)

2. Improvement in Feed Conversion Ratio

Feed represents the largest operational cost in aquaculture, often accounting for 50–70% of total production expenses. Biofloc Technology significantly improves the feed conversion ratio by providing fish with an additional natural source of nutrition. The microbial biomass formed in biofloc systems is continuously available for grazing, thereby supplementing commercial feed. Because fish obtain nutrients from both formulated diets and biofloc particles, less commercial feed is required to achieve the same or greater weight gain. Furthermore, biofloc microorganisms produce digestive enzymes such as proteases, amylases, and lipases that improve feed digestibility and nutrient utilization. Enhanced digestive efficiency results in lower feed wastage, reduced feed costs, and improved production efficiency. Several experimental studies have reported reductions in FCR from approximately 1.8–2.0 in conventional systems to around 1.2–1.5 in well-managed biofloc systems, demonstrating the economic benefits of this technology.[3](Dheeran, et al 2025)

3. Improved Protein Utilization and Nutrient Recycling

Biofloc Technology promotes efficient nutrient recycling within the aquaculture environment. In conventional systems, nitrogen from uneaten feed and fish excretion accumulates as toxic ammonia, which must be removed through water exchange. In contrast, biofloc systems stimulate the rapid growth of heterotrophic bacteria by increasing the carbon-to-nitrogen ratio. These bacteria assimilate ammonia and convert it into microbial protein, which becomes incorporated into biofloc particles. Fish subsequently consume these particles, effectively recycling nutrients that would otherwise be lost. Biofloc biomass generally contains 25–50% crude protein along with essential amino acids, fatty acids, vitamins, minerals, and nucleotides. This efficient recycling improves protein retention, enhances muscle development, reduces nitrogen loss to the environment, and contributes to sustainable aquaculture production.[4](Raza, et al 2024)

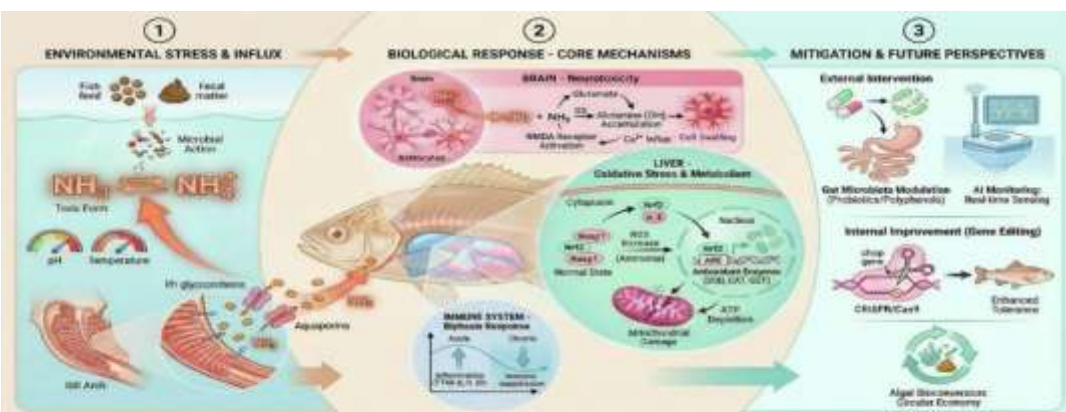

Fig: 1.1 illustrating environmental ammonia generation, its biological effects on the brain, liver, and immune system, and emerging mitigation strategies for sustainable aquaculture.[4](Raza, et al 2024)

4. Enhancement of Digestive Enzyme Activity

The microbial community associated with bioflocs contributes significantly to digestive health by producing extracellular enzymes that facilitate nutrient digestion. Enzymes such as proteases, lipases, cellulases, and amylases improve the breakdown of proteins, fats, carbohydrates, and plant-derived feed ingredients. Increased digestive enzyme activity enhances nutrient absorption in the intestine, leading to improved feed efficiency and growth. In addition, beneficial probiotic bacteria within bioflocs help maintain a healthy intestinal microbiota, suppress pathogenic microorganisms, and improve gut morphology. A healthy gastrointestinal tract supports better nutrient assimilation, immune function, and overall fish health, thereby contributing to enhanced growth performance.[5](Minaz, et al 2025)

5. **Increased Survival Rate**

High survival rates are essential for profitable aquaculture production. Fish cultured in biofloc systems generally exhibit significantly higher survival than those reared in traditional systems. The improved survival is primarily attributed to stable water quality, reduced concentrations of toxic metabolites, enhanced immune responses, and lower disease prevalence. Beneficial microorganisms present in bioflocs compete with pathogenic bacteria for nutrients and attachment sites, reducing the likelihood of disease outbreaks. Furthermore, bioactive compounds such as β-glucans, peptidoglycans, nucleotides, and microbial polysaccharides stimulate innate immune responses, enabling fish to resist infections more effectively. Many studies have reported survival rates exceeding 90–95% in properly managed biofloc systems.[6](Ahmad, et al 2024)

EFFECTS OF BIOFLOC TECHNOLOGY ON WATER QUALITY

1. **Reduction of Ammonia Concentration**

Maintaining low ammonia levels is one of the primary objectives of Biofloc Technology. Ammonia is produced continuously through fish metabolism, excretion, and decomposition of organic matter. In its unionized form (NH_3), ammonia is highly toxic and can damage fish gills, impair respiration, reduce appetite, suppress immune function, and cause mortality. Biofloc systems maintain a high carbon-to-nitrogen ratio, encouraging rapid proliferation of heterotrophic bacteria. These bacteria assimilate ammonia directly into their cellular biomass during microbial growth, thereby preventing toxic accumulation. Consequently, biofloc systems maintain significantly lower ammonia concentrations than conventional aquaculture systems, reducing physiological stress and supporting healthier fish growth.[7](Minaz, et al 2025)

2. **Reduction of Nitrite and Nitrate Levels**

Nitrite is another toxic nitrogenous compound that interferes with oxygen transport by converting hemoglobin into methemoglobin, resulting in "brown blood disease." Although nitrate is less toxic, prolonged exposure to high concentrations may negatively affect fish growth and reproduction. In biofloc systems, microbial communities effectively regulate nitrogen cycling. Heterotrophic bacteria rapidly assimilate ammonia, reducing substrate availability for nitrite formation, while nitrifying bacteria further convert remaining ammonia and nitrite into nitrate under appropriate conditions. Continuous microbial uptake and nutrient recycling help maintain safe concentrations of nitrogenous compounds, improving water quality and fish welfare.[8] (Bossier, et al 2017)

3. **Stabilization of pH**

Water pH is a critical parameter affecting fish physiology and microbial activity. Large fluctuations in pH can impair metabolic processes, reduce feed intake, and increase the toxicity of ammonia. Biofloc systems help stabilize pH through balanced microbial metabolism and continuous nutrient cycling. The production and consumption of carbon dioxide, bicarbonate ions, and other metabolic products create buffering effects that reduce sudden changes in pH. However, because microbial respiration consumes alkalinity, regular monitoring and supplementation with buffering agents such as sodium bicarbonate or agricultural lime may be necessary to maintain pH within the optimal range of 7.0–8.5.[9] (Kumar, et al 2017)

4. **Improvement of Dissolved Oxygen Dynamics**

Biofloc systems require continuous and efficient aeration because both fish and microorganisms consume oxygen during respiration. Although microbial activity increases oxygen demand, adequate aeration maintains dissolved oxygen concentrations above recommended levels (generally >5 mg/L for most fish species).[10] Continuous aeration also keeps biofloc particles suspended in the water column, ensuring uniform distribution of nutrients and preventing sludge accumulation. Proper oxygen management reduces stress, supports microbial metabolism, and promotes optimal fish growth and survival.[11] (Avnimelech, et al 2015)

5. Reduction of Organic Waste Accumulation

In traditional aquaculture systems, uneaten feed and fish feces accumulate on the pond bottom, where they decompose and release toxic gases such as ammonia, hydrogen sulfide, and methane. Biofloc Technology accelerates the microbial decomposition and assimilation of these organic wastes, converting them into useful microbial biomass instead of allowing them to accumulate. This process reduces sludge formation, minimizes harmful gas production, and improves the overall cleanliness of the culture environment. As a result, fish experience lower environmental stress, better health, and improved growth performance.[12] (Tacon, et al 2024)

6. Water Conservation and Environmental Sustainability

A major advantage of Biofloc Technology is its ability to operate with minimal or zero water exchange. Unlike conventional aquaculture systems, which often require daily replacement of large volumes of water, biofloc systems recycle nutrients internally and maintain acceptable water quality through microbial processes. This greatly reduces freshwater consumption and minimizes the discharge of nutrient-rich effluents into surrounding ecosystems. Consequently, BFT contributes to environmental protection by reducing eutrophication, conserving water resources, lowering the ecological footprint of aquaculture, and promoting sustainable fish farming practices, particularly in regions where water availability is limited.[13] (Ballester, et al 2024)

7. Components of Biofloc

Bioflocs consist of a diverse consortium of living and non-living components that function together to maintain water quality and improve fish nutrition. The microbial community is primarily composed of heterotrophic bacteria responsible for ammonia assimilation, nitrifying bacteria involved in nitrogen cycling, phytoplankton, microalgae, fungi, protozoa, rotifers, and beneficial probiotics. In addition to microorganisms, bioflocs contain extracellular polymeric substances, organic detritus, suspended feed particles, and mineral components. The EPS secreted by bacteria acts as a natural adhesive that binds microbial cells into stable floc particles. These aggregates contain proteins, amino acids, vitamins, minerals, fatty acids, enzymes, and nucleotides, making them a valuable natural feed supplement. The composition of biofloc varies according to water quality, stocking density, carbon source, feed composition, and management practices.[14] (Crab, et al 2024)

8. Carbon-to-Nitrogen (C: N) Ratio in Biofloc Systems

Maintaining an appropriate carbon-to-nitrogen ratio is one of the most critical factors determining the success of Biofloc Technology. Heterotrophic bacteria require both carbon and nitrogen for cellular growth. Since commercial aquaculture feeds contain relatively high protein levels but limited available carbon, an external carbon source must be supplied to promote bacterial growth. Increasing the C:N ratio stimulates bacterial assimilation of ammonia into microbial biomass, thereby reducing toxic nitrogen concentrations. Most researchers recommend maintaining a C:N ratio between 15:1 and 20:1 for efficient biofloc formation. Carbon sources commonly used include molasses, cassava flour, wheat bran, corn starch, rice bran, and sugarcane by-products. Appropriate management of the C:N ratio improves microbial productivity, enhances water quality, increases biofloc production, and ultimately supports better fish growth.[15] (Crab, et al 2023)

9. Water Quality Parameters in Biofloc Systems

Water quality management is essential for successful biofloc culture. Optimal water quality ensures healthy microbial activity and supports normal fish physiology. The recommended ranges[16] (Luo, et al 2014)

Parameter	Recommended Range
Temperature	26–32°C
pH	7.0–8.5
Dissolved Oxygen	>5 mg/L
Total Ammonia Nitrogen	<1 mg/L
Unionized Ammonia	<0.05 mg/L
Nitrite	<0.5 mg/L
Alkalinity	100–200 mg/L as $CaCO_3$
Biofloc Volume	10–25 mL/L

10. Future Directions

1. Optimization of Microbial Communities

The effectiveness of Biofloc Technology (BFT) depends largely on the composition and activity of microbial communities responsible for nutrient recycling and water purification. Future research should focus on identifying beneficial microorganisms that contribute to efficient ammonia assimilation, biofloc formation, pathogen inhibition, and nutrient cycling. Modern molecular techniques such as metagenomics, metatranscriptomics, whole-genome sequencing, and microbial metabolomics can be used to characterize microbial diversity and functional genes involved in biofloc ecosystems. Developing species-specific microbial consortia may improve floc stability, enhance feed utilization, strengthen fish immunity, and increase production efficiency. Research should also investigate microbial interactions under different environmental conditions, stocking densities, and culture systems to establish standardized microbial management strategies for commercial aquaculture.[17] (Ray, et al 2010)

2. Development of Sustainable and Low-Cost Carbon Sources

Maintaining the optimal carbon-to-nitrogen (C:N) ratio is one of the most important requirements for successful biofloc formation. Although molasses is commonly used as an external carbon source, its availability and cost may limit its application in some regions. Future investigations should evaluate locally available agricultural residues and agro-industrial by-products such as rice bran, wheat bran, cassava flour, corn starch, sugarcane bagasse, fruit-processing waste, and food industry residues as economical alternatives. Comparative studies should assess their influence on microbial growth, biofloc nutritional quality, water quality, fish performance, and production costs. Identifying sustainable carbon sources will improve the economic feasibility of Biofloc Technology while promoting circular bioeconomy principles through the utilization of agricultural waste materials.[18] (De Schryver, et al 2014)

3. Integration with Recirculating Aquaculture Systems and Aquaponics

Future research should explore the integration of Biofloc Technology with other sustainable aquaculture systems, particularly Recirculating Aquaculture Systems (RAS), aquaponics, and Integrated Multi-Trophic Aquaculture (IMTA). Such integrated production systems have the potential to maximize nutrient recycling, improve water-use efficiency, minimize waste generation, and enhance overall productivity. Combining biofloc microbial communities with biological filtration and plant nutrient uptake may further reduce water exchange requirements and improve environmental sustainability. Long-term comparative studies are required to evaluate the biological performance, economic profitability, energy requirements, and environmental impact of integrated systems under commercial farming conditions.[20] (Wasielesky, et al 2013)

4. Artificial Intelligence (AI), Internet of Things (IoT), and Precision Aquaculture

The application of Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT), and precision aquaculture technologies represents one of the most promising future developments in Biofloc Technology. Smart sensor networks capable of continuously monitoring dissolved oxygen, ammonia, nitrite, nitrate, pH, alkalinity, temperature, turbidity, and biofloc volume can provide real-time information regarding system performance. AI-based predictive models can detect abnormal water quality conditions before they become harmful, allowing automated control of aeration, carbon supplementation, and feeding. Such intelligent monitoring systems can reduce labour requirements, minimize human error, improve production efficiency, and enhance fish welfare while lowering operational costs.[21] (Anand, et al 2014)

5. Long-Term Evaluation of Fish Health, Immunity, and Welfare

Most published studies have evaluated Biofloc Technology over relatively short experimental periods. Future investigations should focus on long-term commercial production cycles to evaluate the effects of biofloc systems on fish physiology, stress response, reproductive performance, immune function, gut microbiota, disease resistance, and overall welfare. Special attention should be given to the interactions between biofloc microorganisms and the intestinal microbiome, as these relationships may influence nutrient absorption, metabolic health, and resistance to infectious diseases. Long-term studies will provide stronger scientific evidence regarding the sustainability and reliability of Biofloc Technology under different climatic and production conditions.[22] (Crab, et al 2010)

6. Improvement of Fish Nutrition and Feed Formulation

Bioflocs serve as an important natural source of proteins, amino acids, fatty acids, vitamins, minerals, enzymes, and probiotics. Future research should investigate methods to enhance the nutritional composition of biofloc biomass through microbial manipulation and nutrient supplementation. Studies should determine the extent to which biofloc biomass can replace commercial fishmeal and other expensive feed ingredients without compromising fish growth or health. Developing optimized feeding strategies that combine formulated diets with biofloc-derived nutrients could reduce feed costs, improve feed conversion ratio (FCR), and enhance sustainable aquaculture production.[23] (Emerenciano, et al 2025)

7. Climate Change Adaptation and Environmental Sustainability

Climate change, freshwater scarcity, and environmental degradation are major global challenges affecting aquaculture production. Future research should evaluate the contribution of Biofloc Technology toward climate-resilient aquaculture systems by reducing freshwater consumption, improving nutrient recycling, minimizing greenhouse gas emissions, and decreasing environmental pollution. Comprehensive life-cycle assessment (LCA) studies should compare the carbon footprint, water footprint, energy consumption, and environmental impacts of biofloc systems with conventional aquaculture practices. Such evidence will strengthen the role of Biofloc Technology in achieving sustainable development and environmental conservation.[24] (Ekasari, et al 2014).

8. Species-Specific Culture Protocols

Different cultured fish and shrimp species exhibit varying responses to Biofloc Technology because of differences in feeding habits, digestive physiology, environmental tolerance, and stocking density requirements. Future research should establish species-specific management protocols for major commercial species such as Nile tilapia, African catfish, common carp, pangasius, Pacific white shrimp, giant freshwater prawn, and marine fish species. Standardized recommendations regarding stocking density, aeration, carbon source selection, feeding frequency, biofloc volume, and water quality management will improve production consistency and facilitate large-scale commercial adoption.[25] (Ray, et al 2010)

9. Economic Analysis and Commercial Scale-Up

Although Biofloc Technology has demonstrated biological and environmental advantages, additional research is required to evaluate its long-term economic viability. Future investigations should include comprehensive cost-benefit analyses comparing investment costs, operating expenses, feed savings, electricity consumption, labour requirements, production yield, profitability, and return on investment under different farming conditions. Economic modelling should also evaluate the financial feasibility of Biofloc Technology for small-scale, medium-scale, and industrial aquaculture enterprises. These studies will support evidence-based decision-making by farmers, investors, and policymakers.[25](Ray, et al 2010)

10. Policy Development, Farmer Training, and Technology Transfer

Successful implementation of Biofloc Technology requires technical knowledge, skilled management, and continuous monitoring of water quality. Future efforts should focus on developing standardized national and international guidelines for Biofloc management, supported by government agencies, universities, research institutions, and extension services. Regular training programmes, demonstration farms, online learning platforms, and technical workshops should be organized to improve farmers' understanding of biofloc principles, microbial management, aeration systems, and water quality monitoring. Strengthening technology transfer and extension services will accelerate the adoption of Biofloc Technology and contribute to sustainable aquaculture development worldwide.[25](Ray, et al 2010)

CONCLUSION

Biofloc Technology represents a major advancement in sustainable aquaculture by integrating biological waste treatment, water quality management, and nutritional supplementation into a single production system. Unlike conventional aquaculture, which depends heavily on frequent water exchange and external waste removal, Biofloc Technology utilizes naturally occurring heterotrophic microorganisms to recycle nitrogenous wastes into valuable microbial biomass. This process not only reduces toxic ammonia and nitrite concentrations but also produces protein-rich bioflocs that serve as an additional natural food source for cultured fish. Consequently, Biofloc Technology improves feed utilization, enhances nutrient recycling, and increases overall production efficiency. The literature reviewed in this article consistently demonstrates that Biofloc Technology has significant positive effects on fish growth performance. Fish cultured in biofloc systems generally exhibit higher final body weight, increased weight gain, improved specific growth rate (SGR), better feed conversion ratio (FCR), enhanced digestive enzyme activity, improved protein utilization, and higher survival rates compared with conventional culture systems. These improvements are largely attributed to the continuous availability of nutrient-rich microbial biomass, improved intestinal health, enhanced digestive capacity, and stable environmental conditions. In addition, bioactive compounds such as β-glucans, probiotics, nucleotides, and microbial polysaccharides present within bioflocs stimulate the innate immune system, increasing resistance to infectious diseases and reducing the need for antibiotics and chemical therapeutics. One of the most important advantages of Biofloc Technology is its ability to maintain excellent water quality through efficient microbial nutrient recycling. By maintaining an appropriate carbon-to-nitrogen ratio, heterotrophic bacteria rapidly assimilate dissolved ammonia into microbial cells, thereby preventing the accumulation of toxic nitrogenous compounds. Biofloc systems also reduce nitrite concentrations, stabilize pH, maintain dissolved oxygen through continuous aeration, decrease organic waste accumulation, and minimize sludge formation. These improvements create a healthier aquatic environment that reduces physiological stress and supports optimal fish growth and survival. Furthermore, the requirement for minimal or zero water exchange significantly conserves freshwater resources while reducing the discharge of nutrient-rich effluents into surrounding ecosystems. From an economic perspective, Biofloc Technology offers considerable benefits by lowering feed costs, reducing water consumption, increasing stocking density, improving production efficiency, and enhancing overall profitability. Environmentally, the technology contributes to sustainable aquaculture by minimizing pollution, reducing nutrient discharge, conserving water resources, and promoting efficient nutrient recycling. These characteristics make Biofloc Technology particularly suitable for regions facing freshwater scarcity and increasing environmental regulations. Despite these advantages, successful implementation of Biofloc Technology requires continuous aeration, regular monitoring of water quality, appropriate management of the carbon-to-nitrogen ratio, and trained technical personnel. Future research should focus on optimizing microbial community composition, evaluating alternative low-cost carbon sources, integrating Biofloc Technology with recirculating aquaculture systems (RAS) and aquaponics, and applying sensor-based automation and artificial intelligence for real-time water quality management. Such developments will further improve production efficiency, environmental sustainability, and commercial feasibility. Overall, the scientific evidence reviewed in this article demonstrates that Biofloc Technology is a reliable, environmentally sustainable, and economically viable aquaculture system that significantly enhances fish growth performance while maintaining superior water quality. Its adoption can contribute to increased aquaculture productivity, improved resource utilization, and long-term sustainable fish production, making it one of the most promising technologies for the future of global aquaculture.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Acknowledgements

The authors sincerely acknowledge Rayat Bahra University, Mohali, Punjab, India, for providing the necessary academic support, research facilities, and a conducive environment for conducting this study. The authors also express their gratitude to the faculty members and staff of the University School of Life Sciences for their valuable assistance and encouragement throughout the course of this research.

REFERENCES

1. Liu, G., Verdegem, M., Ye, Z., Zhao, J., Xiao, J., Liu, X., Liang, Q., Xiang, K., & Zhu, S. (2025). Advancing aquaculture sustainability: A comprehensive review of biofloc technology trends, innovative research approaches, and future prospects. Reviews in Aquaculture. https://doi.org/10.1111/raq.12970
2. Dheeran, P., Anantharaja, K., Campal, E. I., Kara, T., Selvaraj, M., Arisekar, U., Assiri, M. A., & Iswarya, K. (2025). Harnessing biofloc technology: A sustainable paradigm for modern aquaculture – A review. Annals of Animal Science, 25(4).

3. Bibliographic Insight Research Group. (2025). Bibliographic insight of biofloc technology (BFT): Global trend, research hotspots and prospects. Aquaculture, 600, 742251. https://doi.org/10.1016/j.aquaculture.2025.742251
4. Raza, B., Zheng, Z., & Yang, W. (2024). A review on biofloc system technology, history, types, and future economical perceptions in aquaculture. Animals, 14(10), 1489. https://doi.org/10.3390/ani14101489
5. Minaz, M., Yazıcı, İ. S., Sevgili, H., & Aydın, İ. (2024). Biofloc technology in aquaculture: Advantages and disadvantages from social and applicability perspectives – A review. Annals of Animal Science, 24(2), 377–394.
6. Food and Agriculture Organization of the United Nations. (2024). The State of World Fisheries and Aquaculture 2024: Blue Transformation in Action. FAO, Rome.
7. Ahmad, I., Rani, A. M. B., Verma, A. K., & Maqsood, M. (2017). Biofloc technology: An emerging avenue in aquatic animal healthcare and nutrition. Aquaculture International, 25(3), 1215–1226.
8. Bossier, P., & Ekasari, J. (2017). Biofloc technology application in aquaculture to support sustainable development goals. Microbial Biotechnology, 10(5), 1012–1016.
9. Kumar, S., Anand, P. S. S., De, D., Deo, A. D., Ghoshal, T. K., & Sundaray, J. K. (2017). Effects of biofloc technology on growth, digestive enzyme activity, immune response, and water quality in aquaculture systems. Aquaculture International, 25(4), 1621–1636.
10. Pérez-Fuentes, J. A., Pérez-Rostro, C. I., Hernández-Vergara, M. P., Monroy-Dosta, M. C., & Fogel, I. (2016). C:N ratios affect nitrogen removal and production of Nile tilapia in biofloc systems under intensive culture conditions. Aquaculture, 452, 247–251.
11. Avnimelech, Y. (2015). Biofloc Technology: A Practical Guide Book (3rd ed.). World Aquaculture Society.
12. Tacon, A. G. J., & Metian, M. (2015). Feed matters: Satisfying the feed demand of aquaculture. Reviews in Fisheries Science & Aquaculture, 23(1), 1–10.
13. Emerenciano, M., Ballester, E. L. C., Cavalli, R. O., & Wasielesky, W. (2012). Biofloc technology application as a food source in shrimp farming. Aquaculture Research, 43(3), 447–457.
14. Crab, R., Defoirdt, T., Bossier, P., & Verstraete, W. (2012). Biofloc technology in aquaculture: Beneficial effects and future challenges. Aquaculture, 356–357, 351–356.
15. Hargreaves, J. A. (2013). Biofloc Production Systems for Aquaculture (SRAC Publication No. 4503).
16. Luo, G., Gao, Q., Wang, C., Liu, W., Sun, D., Li, L., & Tan, H. (2014). Growth, digestive activity, welfare, and partial cost-effectiveness of genetically improved farmed tilapia cultured in a biofloc system. Aquaculture, 422–423, 1–7.
17. Ray, A. J., Seaborn, G., Leffler, J. W., Wilde, S. B., Lawson, A., Browdy, C. L., & Lotz, J. M. (2010). Characterization of microbial communities in minimal-exchange biofloc aquaculture systems. Aquaculture, 302(1–2), 20–27.
18. De Schryver, P., Crab, R., Defoirdt, T., Boon, N., & Verstraete, W. (2008). The basics of bioflocs technology: The added value for aquaculture. Aquaculture, 277(3–4), 125–137.
19. Verdegem, M. C. J. (2013). Nutrient discharge from aquaculture operations in function of system design and production environment. Reviews in Aquaculture, 5(3), 158–171.
20. Wasielesky, W., Atwood, H., Stokes, A., & Browdy, C. L. (2006). Effect of natural production in a zero-water-exchange suspended microbial floc-based super-intensive culture system for white shrimp. Aquaculture, 258(1–4), 396–403.
21. Anand, P. S. S., Kumar, S., Panigrahi, A., Ghoshal, T. K., Dayal, J. S., Biswas, G., De, D., & Sundaray, J. K. (2014). Effects of C:N ratio and substrate integration on growth, microbial dynamics, immune response, and disease resistance in Penaeus monodon. Fish & Shellfish Immunology, 39(2), 361–367.
22. Crab, R., Chielens, B., Wille, M., Bossier, P., & Verstraete, W. (2010). The effect of different carbon sources on the nutritional value of bioflocs. Aquaculture Engineering, 42(1), 1–9.
23. Emerenciano, M., Cuzon, G., Goguenheim, J., Gaxiola, G., & Aquacop. (2013). Biofloc technology application as a food source in shrimp and fish farming. Aquaculture Research, 44(6), 839–906.
24. Ekasari, J. (2014). Biofloc technology as an integrated approach to sustainable aquaculture. Journal of the Indonesian Aquaculture Society, 9(2), 85–97.
25. Avnimelech, Y. (2010). Carbon/nitrogen ratio as a control element in aquaculture systems. Aquaculture, 176(3–4), 227–235.