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Biofloc Pond Farming: A Systematic Review of the Literature on Advanced Tilapia Aquaculture Practices

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Abstract:
Biofloc technology, an emerging method in contemporary aquaculture, has gained attention for its sustainable application in tilapia farming. By manipulating microbial communities to create dense suspended solids called bioflocs, this approach serves a dual purpose: providing a nutrient source for aquatic organisms and improving water quality by assimilating excess nutrients. The increasing interest in tilapia aquaculture has witnessed a rise in employing biofloc systems due to their potential to enhance growth, reduce feed costs, and lessen environmental impact. This review aims to comprehensively synthesize the most recent research, collected from reputable databases, focusing specifically on biofloc pond farming in advanced tilapia aquaculture. It highlights the advantages, disadvantages, and effectiveness of biofloc pond farming in improving water quality and fish growth, comparing it with traditional aquaculture systems, and identifying key areas for future research and development with a focus on optimizing biofloc composition and management.

Keywords **—Biofloc pond farming, Biofloc technology, Bioflocs, Aquaculture, Tilapia farming, Water quality management, Microbial communities**

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I. INTRODUCTION

Aquaculture, particularly in Asia, is advancing rapidly. The worldwide production of aquaculture is increasing at a rate that surpasses that of animal farming and capture fisheries, the other two major sources of animal protein for the global populace. Consequently, aquaculture is poised to play an increasingly important role in seafood production and is anticipated to eventually become the main source [1]. According to the Food and Agriculture Organization (FAO), the general trend in aquatic animal production conceals substantial disparities across continents, regions, and nations. In 2020, Asian countries emerged as the primary producers, contributing 70 percent to the total, followed by the Americas, Europe, Africa, and Oceania. The growth of aquaculture in recent decades has significantly enhanced the overall yield of aquatic animal production in inland waters, increasing from 12 percent of the total production in the late 1980s to 37 percent in 2020. The fisheries and aquaculture sectors have gained increasing recognition for their vital role in global food security and nutrition [2].

Tilapia, a fish species known for its abundant breeding and economic significance, holds the potential to meet the growing worldwide demand for protein sources [3]. The practice of tilapia farming is extensive, taking place in over 135 countries and territories [4]. Given its adaptability to aquaculture, market appeal, and steady market prices, tilapia presents a viable option for sustainable fish production. The worldwide market for tilapia is expanding at a rate of 10 – 12% annually [5].

Biofloc technology (BFT) is recognized as an eco-friendly approach that ensures suitable water quality for aquatic life, provides additional food and nutrition, and fosters a healthy environment for the animals during the farming period. BFT is also seen as a sustainable system that enhances water quality. The use of BFT also impacts the microbial community and diversity in the biofloc system [6]. Additionally, Biofloc technology (BFT) emphasizes the cultivation of a microorganism community, consolidated in bioflocs (clusters of microorganisms made up of protozoan bacteria, phytoplankton, and zooplankton; all these forms are biofloc). These bioflocs play a crucial role in managing the degradation of toxic substances in water and food residues. Without any water exchange, this leads to higher densities, improves the biosafety of the systems, provides health benefits to the organisms, reduces food consumption and water pumping, and allows the producer to use a smaller area for cultivation [7].

Biofloc technology (BFT) has emerged as a new and key technology for the development of sustainable aquaculture that has been proven for use in the aquaculture of tilapia [6]. The integration of biofloc systems involves deliberately cultivating microbial communities within aquaculture ponds, establishing a dynamic environment that encourages nutrient recycling and effective water quality management. This technology fosters the formation of microbial aggregates, known as bioflocs, enhancing the overall productivity of aquaculture systems while minimizing environmental impact. The application of BFT in tilapia farming not only addresses water quality and waste management issues but also leads to higher production and improved economic viability.

A. Aims

This systematic review aims to comprehensively synthesize the latest research, gathered from reputable databases, on biofloc pond farming in advanced tilapia aquaculture. The primary goal is to provide a comprehensive analysis of the current state of biofloc pond farming for tilapia production, including its benefits and limitations. The review will assess the effectiveness of biofloc technology in enhancing water quality parameters and promoting optimal fish growth. Moreover, it will compare biofloc pond farming with traditional tilapia aquaculture systems in terms of resource utilization, environmental impact, and economic feasibility. Lastly, it will identify and prioritize key areas for future research and development in biofloc technology for tilapia aquaculture, with a particular focus on optimizing biofloc composition and management.

II. METHODOLOGY

A. Systematic Literature Review

Following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), a systematic search was conducted for studies on advanced tilapia aquaculture practices, specifically emphasizing biofloc pond farming [8]. The search results for each step of the PRISMA workflow are shown in Figure 1.

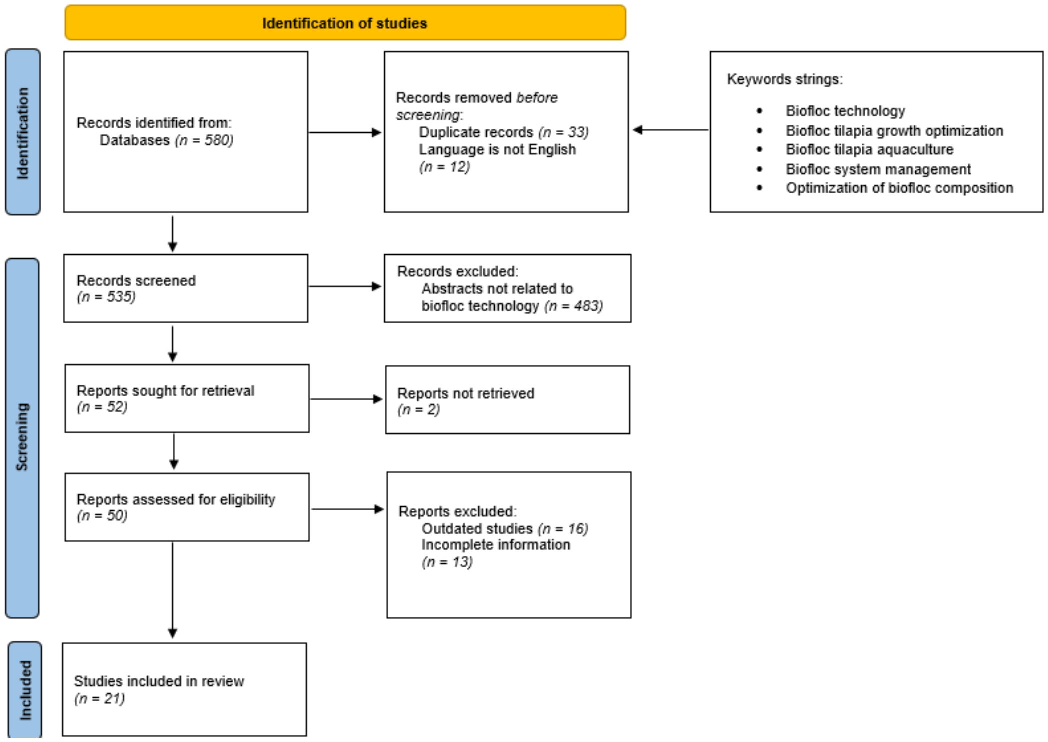

Fig. 1PRISMA Flow Diagram

B. *Data Collection*

Five distinct keyword strings (as illustrated in Figure 1) were used to conduct a comprehensive search across various databases, including PubMed, ScienceDirect, and Google Scholar, focusing on records related to the subject [9]. Before the screening phase, a thorough arrangement was conducted to enhance the dataset. Initial records were acquired from various sources, resulting in a total count. The dataset underwent improvement for subsequent analysis by eliminating duplicate records and excluding records not in English. This ensured a more targeted and relevant dataset for the systematic review [8].

C. *Screening Evaluation*

The screening evaluation involved assessing all articles based on their titles and abstracts. Each identified record underwent a rigorous evaluation to determine its eligibility for inclusion in the systematic review [10]. This involved the application of predefined criteria, resulting in the exclusion of certain records for a more targeted selection. Simultaneously, efforts were made to retrieve reports associated with these records, but not all reports were successfully obtained. Following this, the retrieved reports underwent a thorough eligibility assessment, leading to the exclusion of specific reports based on outlined reasons in the study protocol. The systematic screening process assures a thorough selection of relevant studies for the comprehensive review of advanced tilapia aquaculture practices.

D. *Selection of Studies*

Following the screening process, studies that met the predefined criteria were included in the systematic review. These selected studies form the core of our investigation into advanced tilapia aquaculture practices, with a specific emphasis on biofloc pond farming. The reports associated with these included studies were thoroughly examined and integrated into our review to provide a comprehensive understanding of the topic. This final set of included studies serves as the basis for analyzing and synthesizing the existing literature, contributing valuable insights to the field of advanced tilapia aquaculture [11]. Following the application of the methods, a total of 21 studies were identified as meeting the criteria for inclusion in this systematic review, as depicted in Figure 1. The inclusion criteria ensured that the selected studies aligned with the objectives of our review, enhancing the accuracy and relevance of our findings.

III. RESULTS

The review carefully examined 21 research studies to understand how well biofloc technology (BFT) works in tilapia farming. The findings from these studies have been sorted into four distinct groups, each based on the focus of the study. These categories are determined by the primary goal of each investigation, which includes assessing the advantages and disadvantages of using biofloc BFT, examining water quality in BFT, exploring the growth performance of tilapia, and comparing biofloc pond farming with traditional tilapia aquaculture systems.

The first category examines the pros and cons of integrating biofloc technology into tilapia farming, providing insights into its potential benefits and drawbacks. The second category explores the relationship between biofloc technology and water quality parameters, offering valuable insights into its environmental implications. The third category evaluates tilapia growth within the biofloc system, providing practical insights into the efficiency of biofloc technology. Lastly, the fourth category compares biofloc pond farming with traditional tilapia aquaculture systems, highlighting key distinctions and advantages for those considering different farming methods.

Through this organized categorization, the review aims to provide a comprehensive overview of the various aspects surrounding the use of biofloc technology in tilapia farming, helping both researchers and farmers make informed decisions.

A. Advantages and Disadvantages of Biofloc BFT

In contemporary aquaculture research, biofloc technology (BFT) has emerged as a promising and innovative approach to enhance tilapia fingerling production and overall economic viability. A study by García-Ríos (2019) [12] conducted at Centro Acuicola del Estado de Sonora shed light on the efficacy of BFT with different carbon sources. Notably, sugar as a carbon source demonstrated superior results, yielding the highest tilapia weight. Moreover, the biofloc treatments exhibited lower feed conversion ratios (FCR) compared to traditional systems, signifying enhanced efficiency in resource utilization.Wankanapol (2017) [13] further contributed to the exploration of carbon sources combined with molasses, pinpointing molasses with ground breadcrumb as an optimal combination for biofloc production in tilapia culture. This finding suggests a strategic integration of feed components to achieve optimal results in BFT systems.

Tongsiri's (2020) [14] study added a crucial economic perspective by delving into the cost-benefit analysis of Nile tilapia culture in the biofloc system. The results revealed a favorable benefit-cost ratio (B/C ratio), net present value (NPV), and internal rate of return (IRR), indicating not only the economic feasibility but also the potential for positive returns for fish farmers utilizing biofloc technology. This economic viability adds another layer of significance to the adoption of BFT in tilapia aquaculture.

Nugroho (2023) [15] extended the exploration by comparing biofloc technology with Floating Net Cage (KJA) systems, emphasizing the environmental friendliness of biofloc technology. The study demonstrated that biofloc technology outperformed KJA in terms of productivity, survival rate, and feed efficiency, underscoring its potential as an ecologically sustainable alternative in tilapia aquaculture. However, Fleckenstein's (2020) [16] study introduced a note of caution by highlighting potential challenges with water quality in biofloc systems. It suggested that clear-water or hybrid systems might be more suitable for tilapia nurseries due to superior performance and minimized production costs. This cautious perspective underscores the importance of carefully considering operational conditions and system optimization for the successful implementation of biofloc technology in tilapia aquaculture.

TABLE I
ADVANTAGES AND DISADVANTAGES OF BIOFLOC POND FARMING FOR TILAPIA PRODUCTION

Author	Date	Method	Advantage	Disadvantage
S. Deb, Md. T. Noori, and P. S. Rao	2020	Experimental method	Molasses combined with ground bread crumb was the best carbon source for biofloc production in tilapia culture.	
E. Nugroho, A. Khakim, R. Dewi	2023	Experimental method	The biofloc technology experiment for tilapia culture were 14.81 3.79 kg/m3 (productivity), 72.94 8.17% (survival), 80.66 11.92% (feed efficiency), 3.20 0.63 g/day (ADG), and 16.353 1.017 IDR/kg (production cost).	.
Lombardo García-Ríos, Anselmo Miranda□Baeza, M. Coelho-Emerenciano, José Alberto Huerta-Rábago, Pablo S. Osuna-Amarillas	2019	Experimental method	Biofloc technology can successfully use in tilapia fingerling commercial production with some benefits.	
Sudaporn Tongsiri, Nongnaphat Somkane, Udomluk Sompong,, Daracha Thiammueang	2020	Cost and benefit analysis	The biofloc system for tilapia culture is applicable for fish farmers.	
Leo J. Fleckenstein, Thomas W. Tierney, Andrew J. Ray	2020	Experimental method		Tilapia in hybrid systems had significantly higher average weight and specific growth rate compared to biofloc systems.

B. Water Quality Parameters in BFT

The examined literature provides comprehensive insights into the impact of various carbon sources on water quality parameters in biofloc pond farming, offering a nuanced understanding of their influence on growth performance and biofloc composition. Khanjani's (2021) [17] study assessed the effects of different carbon sources (molasses, starch, barley flour, corn) on water quality, biofloc composition, and growth performance of Nile tilapia. Notably, the study identified variations in dissolved oxygen and pH levels among treatments, emphasizing the importance of carbon source selection in maintaining optimal water conditions for tilapia. Additionally, biochemical composition analysis of biofloc highlighted the distinct effects of carbon sources on protein, lipid, and ash content, underscoring their role in shaping the composition of biofloc.

Rind's (2023) [18] research, focusing on GIFT tilapia fry rearing, emphasized the significance of rice bran as a carbon source. The study found that all water quality parameters remained within acceptable ranges for tilapia fry rearing across different carbon treatments. The significantly higher biomass in the treatment using rice bran suggests its effectiveness in supporting growth. Furthermore, the observed lower water volume requirement in the rice bran treatment indicates a potential impact on the biofloc system's water dynamics, contributing to a more resource-efficient cultivation approach.

Zidni's (2019) [19] investigation into aquaponics biofloc maintenance media highlighted the importance of water quality for supporting the growth productivity of catfish and tilapia. The study focused on minimizing toxic content and maintaining water quality values within acceptable thresholds. The incorporation of aquaponic cultivation using biofloc was identified as a promising strategy to reduce toxic content in both maintenance media and surrounding cultivation areas, thereby contributing to improved water quality.

Wankanapol (2017) [13] study explored the selection of appropriate carbon sources for tilapia culture in a biofloc system. While monitoring water quality parameters twice a day, the study found no significant differences in weight gain, survival rate, average daily weight gain, and specific growth rate among treatments. However, the study identified molasses combined with ground breadcrumb as the optimal carbon source, resulting in the highest feed conversion ratio and total suspended solids. This underscores the intricate relationship between carbon source selection and water quality dynamics in biofloc systems.

In Sgnaulin (2020) [20] experiment focusing on the growth of GIFT tilapia juveniles in biofloc systems, water quality parameters consistently remained within favorable ranges for tilapia culture. The study demonstrated that biofloc, especially in treatments with added glucose (BFG) and molasses (BFM), significantly enhanced the average body weight, length, specific growth rate, and crude protein content. This suggests that biofloc positively influences not only growth parameters but also the nutritional quality of tilapia, contributing to its overall well-being.

Collectively, these studies underscore the importance of biofloc pond farming in maintaining suitable water quality conditions for the successful rearing of tilapia fry and juveniles. The findings emphasize the versatility of biofloc systems in adapting to different carbon sources while sustaining optimal water quality parameters crucial for the growth and well-being of tilapia in aquaculture.

TABLE III
WATER QUALITY PARAMETERS

Author	Date	Water quality
Mohammad Hossein Khanjani, Morteza Alizadeh, Moslem Sharifinia	2021	Different carbon sources, such as rice bran, have been found to be effective in rearing tilapia fry in biofloc systems.
I. Ahamed and A. Ahmed	2021	The use of sodium bicarbonate and calcium hydroxide is effective on the alkalinity and pH adjustments during Nile tilapia nursery on BFT systems.
I. Zidni, Iskandar, I. D. Buwono, Benedikta Prasiwi Mahargyani	2019	The quality of water in maintenance media using aquaponics biofloc gives good water quality values on maintenance media and is still within the threshold for the growth of catfish and tilapia.
Arnuparp Wankanapol, P. Chaibu, Sirichat Soonthornvipat	2017	The nutritional quality of biofloc was appropriate for tilapias.
M. Menagaa, S. Felixb,, M. Charulathaa, A. Gopalakannana, A. Panigrahic	2019	Biofloc formed with added glucose or molasses can enhance growth.

C. Tilapia Growth Performance

The literature on tilapia growth performance in biofloc pond farming systems presents a comprehensive overview of key factors influencing the success of aquaculture practices. Aliabad's study (2021) [21] highlights the superiority of biofloc technology (BFT) over pure water conditions in a 98-day experiment with young Nile tilapia fingerlings. The BFT-reared tilapia exhibited remarkable improvements in growth metrics, including final weight, weight gain, average daily gain, and specific growth rate, underscoring the efficacy of biofloc systems in promoting robust tilapia development. Additionally, the study revealed positive impacts on immune responses and oxidative stress tolerance, indicating the potential of BFT for intensive tilapia rearing.

Putra's research in 2019 delves into the influence of different carbon sources on the growth and survival of red tilapia in biofloc systems. Notably, the addition of molasses emerged as the most favorable treatment, resulting in superior growth, feed consumption, and survival rates. This study emphasizes the significance of careful carbon source selection in biofloc pond farming, as it plays a pivotal role in optimizing the overall performance of tilapia cultivation [22].

Liu's extensive 2018 feeding trial explores the effects of various stocking densities on the growth, immune responses, and antioxidant status of Oreochromis niloticus fingerlings in a zero-water exchange biofloc system. Lower stocking densities demonstrated superior outcomes in terms of final body weight, digestive enzyme activities, and immune and antioxidant abilities. The study provides crucial insights into mitigating crowding stress in biofloc systems, showcasing their potential to maintain a conducive environment for tilapia growth and overall well-being. Collectively, these studies contribute valuable knowledge to enhance the efficiency and sustainability of tilapia aquaculture through biofloc pond farming practices [23].

TABLE IIIII
TILAPIA GROWTH PERFORMANCE

Author	Date	Method	Growth Rate
[M. Hossein Khanjani, M. Alizadeh, M. Mohammadi, and H. Sarsangi Aliabad	2021	Experimental method	Tilapia raised in biofloc systems exhibited better growth and immune responses compared to those in pure water
I. Putra, I. Effendi, I. Lukistyowati, U. Tang	2019	Experimental method	The best growth, feed consumption, and survival of red tilapia were obtained in treatment B (molasses).
Gang Liu, Zhangying Ye, Dezhao Liu, Jian Zhao, Elayaraja Sivaramasamy, Yale Deng, Songming Zhu	2018	Experimental method	High stocking density reduced growth performance and increased FCR of tilapia in the biofloc system.
M. de, Juan Fernando García□Trejo, V. Caltzontzin-Rabell, R. Chávez-Jaime, Luz, and O. Alatorre-Jácome	2018	Experimental method	The probiotics did not show significant effects in growth but improved the tilapia organism's survival.
L. M. Laice et al.	2020	Experimental method	The average body weight and length of tilapia were significantly high.

E. Biofloc Pond Farming and Traditional Tilapia Aquaculture Systems

The comparison between biofloc pond farming and traditional tilapia aquaculture systems reveals distinct approaches in promoting sustainable and efficient fish production.

In biofloc pond farming, Haraz's study (2018) [24] demonstrates the effectiveness of biofloc technology (BFT) in enhancing the growth performance of Nile tilapia. The BFT system significantly improves final weight, weight gain, average daily gain, and specific growth rate compared to traditional pure water culture. Furthermore, biofloc technology exhibits benefits in immune response and oxidative stress mitigation, as indicated by variations in plasma protein, globulin levels, and superoxide dismutase activity. Jamal's review (2020) [25] further emphasizes the potential of BFT in optimizing aquaculture productivity by efficiently utilizing microbial biotechnology to treat nitrogen components and convert them into valuable proteins for supplementary feeds. The technology enables intensive culture with limited water exchange, high stocking density, aeration, and biota, providing a promising avenue for sustainable aquaculture.

Mugwanya's review (2020) [26] highlights biofloc technology as a promising and sustainable aquaculture system that addresses the challenges of resource limitation, environmental impact, and economic constraints. BFT integrates intensive aquatic species culture, zero water exchange, and improved water quality through beneficial microbial biomass activity. Additionally, BFT facilitates the implementation of integrated multi-trophic aquaculture (IMTA), where waste from one organism serves as feed for another, promoting ecological sustainability. This underscores the significance of biofloc systems for sustainable production and resource utilization in aquaculture.

Contrastingly, traditional aquaculture farming, as exemplified by David's study (2020) [27], faces challenges related to economic, social, and environmental concerns. The study emphasizes the dependence of tilapia cage farming on resources from the economy, with feed being a major contributor. The traditional aquaculture system's sustainability is improved by reducing stocking density, feed rate, and incorporating periphyton as a complementary food source. Similarly, Tom's study (2021) [28] acknowledges the major challenges posed by traditional aquaculture, including water quality issues and secondary pollution. The study compares various aquaculture wastewater treatment technologies, emphasizing the importance of improving water recycling efficiency and reducing wastewater discharge for sustainable aquaculture.

Xu's overview (2018) [29] provides insights into the historical development of China's tilapia farming industry, showcasing the role of science and technology in upgrading and revolutionizing traditional aquaculture practices. While traditional aquaculture has played a significant role in meeting global food demands, advancements in technology are crucial for ensuring sustainability, reducing environmental impact, and improving overall efficiency in the tilapia farming industry.

In summary, the comparison between biofloc pond farming and traditional aquaculture systems highlights the innovative and sustainable features of biofloc technology, offering a promising alternative to address the challenges associated with traditional practices in tilapia aquaculture.

TABLE IVv
COMPARISON BETWEEN BIOFLOC POND FARMING AND TRADITIONAL TILAPIA AQUACULTURE SYSTEMS

	Biofloc Pond Farming	Author	Date	Traditional aquaculture system	Author	Date
Resource utilization	The floc biomass provides a complete source of nutrition for aquatic organisms	Yasmeen G. Haraz, W. N. El-Hawarry, Ramy M. Shourbela	2018	Traditional aquaculture systems of tilapia farming, such as cage farming in Brazil, have been found to be highly dependent on resources from the economy, particularly feed.	Luiz Henrique Castro David, Sara Mello Pinho, Fabiana Garcia	2020
Environmental impact	Biofloc technology is a technique of enhancing water quality in aquaculture through balancing carbon and nitrogen in the system.	M.T. JAMAL et al.	2020	Conventional aquaculture systems is eco-friendly	A. P. Tom, J. S. Jayakumar, M. Biju, J. Somarajan, and M. A. Ibrahim	2021
Economic feasibility	Biofloc technology is cost-effective, it provides a financially viable alternative for aquaculture operations.	Muziri Mugwanya, Mahmoud A. O. Dawood, Fahad Kimera and Hani Sewilam	2020	Tilapia producers have been found to under-utilize feed, fingerlings, and fertilizer, while over-utilizing labor	P. Xu and M. Junchao	2018

IV. DISCUSSION

The exploration of biofloc technology (BFT) in tilapia farming is situated within a context of increasing interest in sustainable aquaculture practices. With aquaculture playing a crucial role in meeting global demand for fish, BFT has emerged as an innovative approach to enhance productivity while minimizing environmental impact. The comprehensive review of 21 research studies serves as a valuable resource for both researchers and farmers seeking a thorough understanding of the implications associated with BFT adoption.

The first category of findings critically examines the advantages and disadvantages of integrating BFT into tilapia farming. García-Ríos (2019) [12] and Wankanapol (2017) [13] contribute noteworthy insights, highlighting the economic viability and enhanced feed efficiency associated with BFT. The strategic integration of feed components, particularly the use of carbon sources such as sugar and molasses, emerges as a pivotal factor influencing optimal results in BFT systems.

The second category delves into the intricate relationship between biofloc technology and water quality parameters. Studies by Khanjani (2021) [17] and Rind's (2023) [18] underscore the importance of carbon source selection in maintaining optimal water conditions for tilapia. Variations in dissolved oxygen, pH levels, and biochemical composition underscore the significance of understanding water quality dynamics in biofloc systems. The findings reveal a delicate balance in carbon source utilization, impacting not only growth performance but also the overall health and well-being of tilapia in aquaculture.

Moving to the third category, there's an in-depth evaluation of tilapia growth performance within biofloc systems. Aliabad's study (2021) [21] demonstrates the superiority of BFT over pure water conditions, showcasing remarkable improvements in growth metrics, immune responses, and oxidative stress tolerance in BFT-reared tilapia. Putra's research in 2019 further emphasizes the pivotal role of careful carbon source selection in optimizing overall performance, with molasses emerging as a favorable treatment for superior growth, feed consumption, and survival rates [22].

The fourth category involves a comparison between biofloc pond farming and traditional tilapia aquaculture systems, providing insights into the contrasting approaches for sustainable fish production. Haraz (2018) [24] and Jamal (2020) [25] highlight the effectiveness of BFT in enhancing growth performance, immune response, and oxidative stress mitigation in Nile tilapia. In contrast, traditional aquaculture, exemplified by David's study (2020) [27], faces challenges related to economic, social, and environmental concerns.

Expanding on the economic aspects, it is crucial to consider the financial implications of adopting BFT in tilapia farming. García-Ríos (2019) [12] study, in particular, emphasizes the economic viability of BFT, suggesting potential cost savings and increased profitability for farmers. The strategic use of carbon sources in BFT systems not only improves feed efficiency but also contributes to economic sustainability in tilapia farming.

An integral aspect of the discussion surrounds the environmental impacts of both biofloc technology and traditional aquaculture. The review underscores the environmental benefits of BFT, such as reduced water usage and nutrient recycling, contributing to a more sustainable and eco-friendly approach compared to conventional methods. This aligns with global efforts to promote responsible and environmentally conscious aquaculture practices.

From a practical standpoint, the review offers valuable insights for farmers considering the adoption of BFT. The emphasis on optimal carbon source selection, as highlighted by various studies, provides actionable guidance for farmers seeking to maximize growth performance, minimize resource inputs, and enhance overall productivity in tilapia farming. This practical orientation is crucial for the successful implementation of BFT on a commercial scale.

It is essential to acknowledge the challenges associated with BFT adoption. The review sheds light on potential hurdles, such as the need for meticulous water quality management and system optimization. These challenges underline the importance of continuous monitoring, research, and adaptation to ensure the long-term success and sustainability of BFT practices in tilapia farming.

In conclusion, the review not only underscores the promising and innovative features of biofloc technology but also emphasizes the need for cautious considerations, particularly in water quality management and system optimization. As the aquaculture landscape continues to evolve, the findings collectively contribute to the ongoing dialogue surrounding sustainable aquaculture practices. The comprehensive nature of the review guides stakeholders towards more informed and environmentally responsible approaches in tilapia farming. Future research directions may focus on refining BFT methodologies, addressing emerging challenges, and further optimizing the integration of this technology into mainstream aquaculture practices.

V. CONCLUSION

The systematic review of 21 research studies on biofloc pond farming in advanced tilapia aquaculture provides a robust foundation for concluding that biofloc technology (BFT) offers significant benefits and holds immense promise for the sustainable development of tilapia farming. The synthesis of diverse studies, categorized into distinct groups, offers a holistic understanding of the multifaceted implications of BFT, aiding both researchers and farmers in making informed decisions.

In the evaluation of the advantages and disadvantages of integrating BFT into tilapia farming, the research, notably by García-Ríos (2019) [12] and Wankanapol (2017) [13], underscores the economic viability and enhanced feed efficiency associated with BFT. The strategic integration of feed components, particularly the use of specific carbon sources like sugar and molasses, emerges as a crucial factor influencing optimal results in BFT systems. This economic efficiency and resource optimization contribute significantly to the appeal of biofloc pond farming.

The examination of the intricate relationship between biofloc technology and water quality parameters, as highlighted in studies by Khanjani (2021) [17] and Rind (2023) [18], further reinforces the positive impact of BFT. The findings emphasize the importance of carbon source selection in maintaining optimal water conditions for tilapia. Variations in dissolved oxygen, pH levels, and biochemical composition underscore the significance of understanding water quality dynamics in biofloc systems. This delicate balance in carbon source utilization not only influences growth performance but also enhances the overall health and well-being of tilapia, further establishing BFT as a beneficial technology.

The in-depth evaluation of tilapia growth performance within biofloc systems, as presented in studies by Aliabad (2021) [21] and Putra (2019) [22], demonstrates the superiority of BFT over pure water conditions. The remarkable improvements in growth metrics, immune responses, and oxidative stress tolerance in BFT-reared tilapia highlight the efficacy of biofloc systems in promoting robust development. The careful selection of carbon sources, with molasses emerging as a favorable treatment, further optimizes overall performance, showcasing BFT as a valuable tool for efficient tilapia cultivation.

The comparison between biofloc pond farming and traditional tilapia aquaculture systems provides conclusive evidence of the innovative and sustainable features of BFT. Studies by Haraz (2018) [24] and Jamal (2020) [25] underscore the effectiveness of BFT in enhancing growth performance, immune response, and oxidative stress mitigation in Nile tilapia. In contrast, traditional aquaculture, as exemplified by David's study (2020) [27], faces challenges related to economic, social, and environmental concerns. The need for reducing stocking density, feed rate, and incorporating periphyton as a complementary food source emerges as a strategy to enhance sustainability in traditional aquaculture.

In conclusion, the cumulative evidence from the systematic review strongly supports the contention that biofloc pond farming is beneficial for tilapia aquaculture. Its economic viability, resource efficiency, positive impact on water quality, and superior growth performance position BFT as a promising and sustainable alternative to traditional aquaculture practices. The findings from this review not only contribute valuable insights to the ongoing dialogue on sustainable aquaculture but also pave the way for future research and development, particularly in optimizing biofloc composition and management for further enhancing the efficiency of tilapia farming.

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