EMPOWERING SUSTAINABLE AQUACULTURE ENTERPRISES: UNVEILING THE POTENTIAL OF BIOFLOC TECHNOLOGY IN INVESTMENTS, COMPLIANCE, AND GROWTH STRATEGIES

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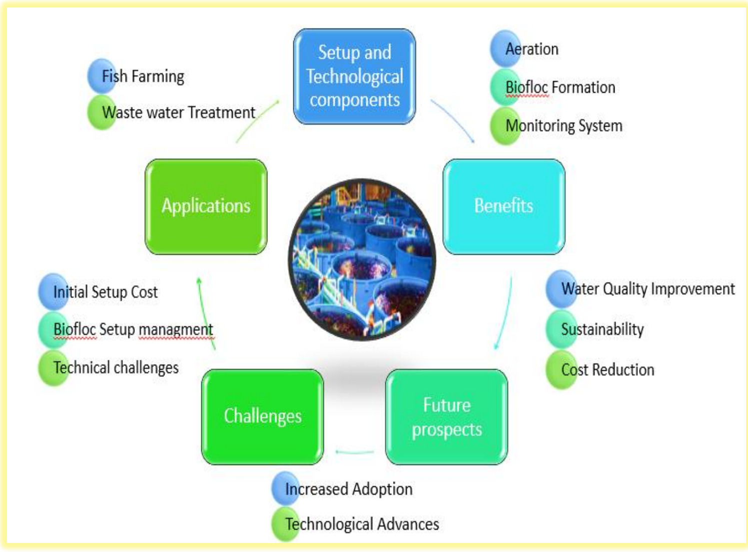
ABSTRACT

Biofloc fish farming, an evolutionary approach and emerging trend of modern aquaculture, is gaining importance in the recent epoch. Biofloc is a true game-changer invention in present-day aquaculture farming because it maximizes productivity, preserves aquatic and terrestrial resources, and is responsible for higher financial returns. The main factors for the adoption of biofloc are examined in this project, along with the challenging factors farmers and other stakeholders encounter in the successful implementation of this technology. The findings of the current study revealed that through the adoption of biofloc farming, farmers may increase fish production by up to three times, drastically reduce the usage of water as it is based on zero water exchange technology, reduce the feed cost, decrease the mortality rate by enhancing fish health. By reducing waste discharge and intelligent resource use, biofloc farming not only maximizes economic efficiency but also decreases environmental deterioration. Biofloc is an economically feasible and sustainable substitute for conventional aquaculture that satisfies the circular economy's principles and the urgent demand for environment-friendly methods. But even with its obvious benefits, problems still exist. Extensive adoption is fraught with high investment costs for set up, feed quality issues related to crude protein level, a lack of technical know-how, higher electricity bills, and limited access to training. The current study identified that financial incentives, easy loans for set-ups, subsidies on electricity bills, reliable monitoring systems, provision of good quality fish seed and fish feed are indispensable for the future success of biofloc farming in Pakistan. Currently, Pakistan's aquaculture sector is burdened by high operational costs, particularly due to feed expenses, which account for 60–70% of production costs. Additionally, shortage in water resources and poor waste management are critical challenges that limit productivity and sustainability, in this scenario, Biofloc Technology (BFT) appears as a blue revolution and climate-smart technology to tackle these issues. BFT systems use microbial flocs to convert organic waste into protein-rich biomass, creating a self-sustaining ecosystem. To fully realize the potential of biofloc technology, however, major challenges still need to be addressed, including the lack of policies for biofloc farming, lack of incentives and subsidies, and false beliefs about the technology.



PREFACE

Aquaculture is one of the industries with the greatest rate of growth in the global economy and is vital to food security because of the growing demand for foods high in protein. A record 214 million tons of aquaculture were produced worldwide in 2020, bringing about $200 billion a year. However, the high water use, frequent disease outbreaks, and environmental deterioration are putting more and more strain on traditional aquaculture technologies. This necessitates creative solutions that can handle sustainability issues and satisfy rising needs. Presenting Biofloc Technology (BFT), a ground-breaking technology that has the power to revolutionize aquaculture. According to this report, "Empowering Sustainable Aquaculture Enterprises: Unveiling the Potential of Biofloc Technology in Investments, Compliance, and Growth Strategies," biofloc technology has the potential to be a driver of long-term economic expansion.

Aquaculture initiatives can reduce fertilizer waste, use land and water more competently, and adhere to stricter environmental requirements by incorporating biofloc systems. The unique feature of biofloc is its capacity to produce microbial protein as a feed source, which significantly lowers operating expenses while growing output. Both farmers and investors find it to be a compelling solution because of its simplicity and scalability. The economic benefits outweigh the environmental benefits. For contemporary aquaculture, biofloc technology provides an ascendable and lucrative route by lowering expenses and raising yields. The report also emphasizes how important market diversification, training, and regulatory support are in eliminating adoption hurdles. With a prominence on Punjab, Pakistan's regulatory structure, the study offers practical advice to assist aquaculture businesses in overcoming compliance obstacles.

This study presents a plan for achieving long-term ecological and economic resilience in addition to food security by reconsidering aquaculture using biofloc technology. It acts as a rallying cry for industry participants to embrace innovation so aquaculture may flourish in a world that is changing quickly.

Without the indispensable advice and mentorship of Dr. Abdul Salam Lodhi (Professor, BUITEMS, Quetta) and Mr. Zafar ul Hassan (Joint Chief Economist, Ministry of Planning, Development & Special Initiatives, Government of Pakistan), this research would not have been practicable. Their knowledge and support have greatly improved the reported work.

We are extremely grateful to Mr. Mursaleen Ahmad, and Mr. Imran, a biofloc, committed farmers and biofloc technology consultanst, for their invaluable advice and practical insights during this study. Their practical expertise and thoughtfulness have contributed priceless viewpoints that influenced the study's conclusions.

Dr. Syed Sikandar Habib, who functioned as a research assistant on this project, is also the recipient of our thanks. This study would not have been probable without his careful attention. We are also deeply grateful for the financing and support provided by the RASTA Competitive Grants Programme for Policy-Oriented Research and the Pakistan Institute of Development Economics (PIDE). Lastly, I would like to express my gratefulness to the farmers, legislators, and other stakeholders who contributed their knowledge and experience, enabling this research to be a genuinely cooperative endeavor.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Aquaculture has been the fastest-growing segment of global food production for the past thirty years, now supplying over half of the fish consumed worldwide (Subasinghe, 2017). Asia accounts for 90 percent of aquaculture production, and the volume is predicted to double by 2050.This industry plays a vital role in ensuring food security, generating income, and supporting community economic development (Little et al., 2016). An estimated 58.5 million people are directly employed in the aquaculture industry, while associated industries and services contribute 100 million jobs globally. Therefore, sustainable aquaculture systems are crucial. The contribution of global aquaculture to world fish production has consistently increased, reaching 46.0 percent, with the production of farmed aquatic animals growing at an average rate of 5.3 percent per year from 2001 to 2018 (FAO, 2020). By 2030, it is expected that freshwater species such as carp and catfish will make up the majority (62 percent) of global aquaculture production (FAO, 2016 and 2020). The sector's rise to global significance has generated interest in its potential to drive economic growth and reduce poverty in developing countries (Little et al., 2012). Aquaculture provides greater income opportunities for small-scale commercial fish farming (Wuyep & Rampedi, 2018).

However, aquaculture's growth is hindered by certain challenges, including unavailability of suitable and cost-effective feed, water shortage, decreasing water resources, excessive dependence on fish meal for aquatic feed preparation, prevalence of diseases, and pollutants arising from effluents emerging from cultivation farms. Researchers are always on the lookout for new ways to make aquaculture more sustainable and eco-friendly (Fasolin et al., 2019). Some cutting-edge systems they've come up with include biofloc technology (BFT), recirculatory aquaculture systems (RAS), raceway systems, integrated aquaponics, and integrated aquaculture (Zimmermann et al., 2023). Among these, biofloc technology really stands out. It's known for cutting down on water use, cleaning up waste efficiently, improving feed conversion ratios, boosting stocking density, and optimizing overall system performance (Khanjani et al., 2023).

By itself, Biofloc Technology (BFT) resembles a micro-ecosystem. Biofloc technology (BFT) is a problem-solving evolutionary technology for traditional aquaculture's difficult issues. Biofloc farming is based on a self-nutrification process as it converts the leftover feed, waste and fish fecal material into edible aggregates known as bioflocs with the help of microorganisms. Biofloc farming along with decreasing the cost and dependency on large quantities of fish feed, wisely conserves the land and water, making it economically viable and environmentally friendly. One-acre pond fish can be raised efficiently in a smaller tank with a diameter of 16-20 with almost zero water exchange (Das et al., 2022).

Nitrogen waste production from organic sources is one of the most enduring challenges in traditional aquaculture, as improper management can lead to poor water quality and fish mortality (Rind et al., 2023). Biofloc technology provides a straightforward yet efficient solution to this issue by converting the nitrogenous waste into bacterial biomass (Minabi et al., 2020). A biofloc system may contain 10^6 to 10^9 bacteria per centimeter cube of water, working like a mini biotechnological industry. Carbon-rich and protein-poor materials are added to system to maintain a C/N ratio higher than 10, which will propel bacteria to use nitrogen present in water. Heterotrophic bacteria are the true heroes of this process, and this encourages their spread. According to Avnimelech (2009), these bacteria alter nitrogen molecules into microbial protein, which is an excellent and sustainable substitute for conventional fish feed protein.

BFT significantly improves aquaculture systems' water quality by lowering ammonia levels, clearing the air of adjourned particles, and making the water better for fish life. By recycling nutrients and reducing water exchange, this method stresses environmental sustainability in addition to cumulative output. It's a cutting-edge farming technique that meets all the requirements of contemporary aquaculture and resource efficacy (Deswati et al., 2022; Liu et al., 2019).

Due in great part to its advantages over predictable semi-intensive methods in terms of biosecurity and environmental impact, closed aquaculture systems are becoming more and more popular worldwide. BFT offers a feasible and sustainable way to increase aquaculture output, making it a suitable fit for this trend (Habib et al., 2023). It's a strategy that supports the drive to meet sustainable development objectives while minimizing expenses and environmental effects (Mordenti et al., 2014).

Aquaculture has huge potential to promote sustainable food production and economic affluence in developing nations like Pakistan (Kausar, 2017). Pakistan has a wealth of aquatic resources, including a large number of rivers, lakes, and coastal regions. But historically, the aquaculture industry in the nation has depended on outdated and traditional agricultural practices (Laghari, 2018). This has made it more problematic for it to satisfy growing demand. Innovative technologies like BFT are obviously the way to go in order to stay up to date (Habib et al., 2022).

Freshwater accessibility and quality are two of Pakistan's major aquaculture challenges. The water use of conventional freshwater agricultural techniques is a startling 16.9 cubic meters per kilogram of output. Its efficiency is indisputable when compared to BFT systems, which require as low as 0.071 to 6.8 cubic meters per kilogram (Mordenti et al., 2014). Because of this, biofloc arrangements are particularly useful in semi-arid areas where water shortage is a major problem. Moreover, BFT is adaptable, allowing farmers from a variety of geographic and economic backgrounds to use it in both big commercial processes and small-scale fish farms.

BFT's financial returns go much beyond water conservation. Biofloc systems offer jobs in the aquaculture industry by treading up aquaculture processes. This might be a game-changer for a nation like Pakistan, which is working to reduce poverty and achieve economic stability. BFT promotes investment in aquaculture-related enterprises and free enterprise, especially in rural areas where economic growth is most required. Cost-effectiveness and productivity can rise dramatically for small-scale farmers, increasing their earnings and standard of living.

This study investigated how biofloc technology is revolutionizing the aquaculture industry in Pakistan. It focuses on how BFT can stimulate investment, guarantee adherence to regulations, and open doors for expansion. BFT is a viable, creative, and workable approach that has the potential to revolutionize aquaculture in Pakistan by tackling important issues, including disease management, resource efficiency, and water shortage.

With an emphasis on investments, regulatory compliance, and growth strategies, this study has attempted to investigate how BFT might support sustainable aquaculture businesses in Pakistan. The particular goals consist of:

(a) Evaluating biofloc technology's economic feasibility as a potential investment for Pakistani aquaculture companies.

(b) Examining how compliance constraints and regulatory environments affect the uptake of biofloc technology in various Punjab, Pakistan, regions.

(c) Offering suggestions and strategic insights for using biofloc technology into aquaculture growth plans to improve profitability, operational effectiveness, and environmental sustainability.

LITERATURE REVIEW

Aquaculture, the fastest-growing food production sector, addresses the critical global challenges of food security, malnutrition, and sustainable resource management in an impressive manner. 49% of global fish consumption Comes from the aquaculture sector**,** which has grown significantly from just 4% in the 1950s (FAO, 2022). This remarkable expansion highlights aquaculture's pivotal role in providing affordable, nutrient-rich food to a rapidly growing population. In regions like South Asia, where dietary protein deficiencies are common, aquaculture has become a cornerstone of rural livelihoods, economic growth, and nutrition.

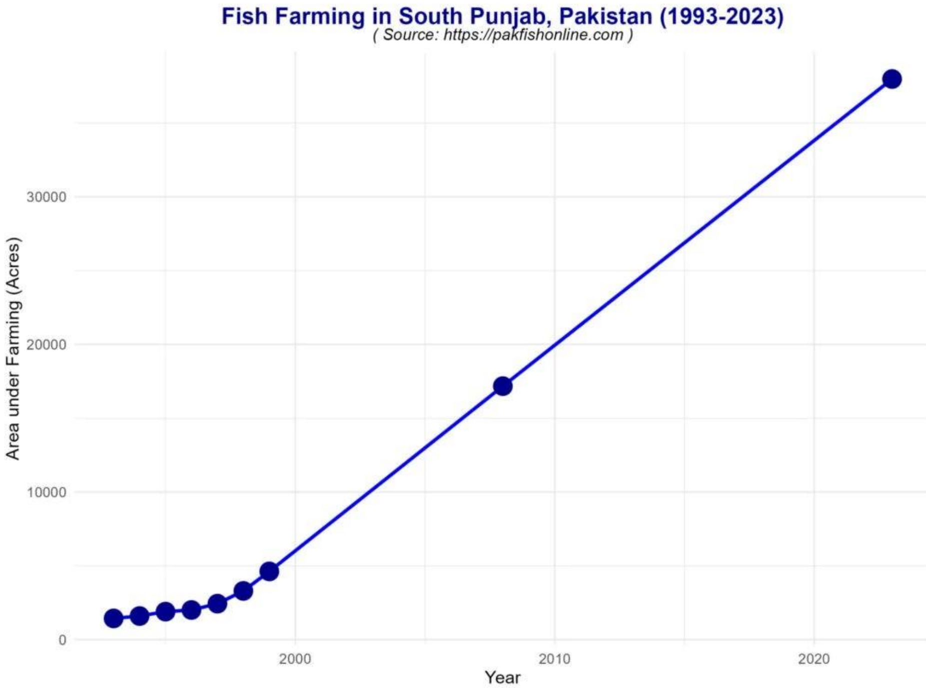
In South Asia, aquaculture contributes significantly to the fisheries sector. Pakistan is sitting on a goldmine of aquatic resources with 1120 kilometers of coastline along with an exclusive economic zone that extends 350 nautical miles into the sea (Jarwar, 2008; Wasim & Abbas, 2024). Despite this natural advantage, fish production in Pakistan still lags far behind regional aquaculture dynamos like India and Bangladesh due to a mix of social and economic factors. India leads with 9.4 million tonnes of aquaculture production (Table.1), making up 65.1% of its total fisheries output. Bangladesh follows with 2.6 million tonnes, representing 55.1% of its fisheries production. Pakistan lags with 817,000 tonnes, which accounts for only 24.8% of its total fisheries output (Pakistan Fisheries Development Board, 2020).

Table 1: Comparison of Fisheries and Aquaculture Production

Country	Total Fisheries Production (Tonnes)	Aquaculture Production (Tonnes)	Aquaculture Contribution (%)	GDP Contribution (%)
India	15.72 million	9.4 million	65.1%	1.1%
Bangladesh	4.51 million	2.6 million	55.1%	3.57%
Pakistan	665,371	817,000	24.8%	<1%

In the 1970s, Pakistan began focusing on developing its inland fishery and aquaculture sectors. Aquaculture production in Pakistan has experienced significant growth during the 21st century, becoming a substantial contributor to the country economy. Over this period, the sector has expanded manifold, playing an increasingly vital role in national food security and economic stability. Semi-intensive aquaculture is widely practiced in Pakistan, focusing on species like Catla catla, Labeo rohita, Cirrhinus mrigala, Hypophthalmichthys nobilis, Ctenopharyngodon idellus, Cyprinus carpio, and Hypophthalmichthys molitrix. Among these, Cirrhinus mrigala, Catla catla, and Labeo rohita command higher market prices due to consumer demand. Nile tilapia, Catfishes, and Snakeheads are also being cultivated, with tilapia development initiatives introduced by the Fisheries Development Board in 2014 to enhance culture techniques and quality (Javed & Abbas, 2018). Species like Tor tor, Schizothorax richardsonii, Lates calcalifer, Tenualosa ilisha, Rita rita and Mystus seenghala also hold potential for aquaculture in Pakistan (Laghari, 2018). However, production levels are still insufficient for national supply or export.

Figure 1: Fish Farming Trend in Punjab, Pakistan



Major hurdles like power outages, poor feed quality, and high construction costs continue to hold back aquaculture progress. Most of the biofloc fish farmers do not have access to modern-day technologies, lack training related to biofloc system, and lack investment and technical knowhow of system, which is the main reason for a reduction in fish yield (Ahmad & Farooq, 2010; Meeran, 2000).

2.1. Biofloc Technology: Transforming Aquaculture Practices

Biofloc technology is an innovative and transformative solution for most of the critical challenges of aquaculture, including higher food requirements and feed costs, bad impact on the environment and scarcity of aquatic resources. Biofloc setup acts as a mini biotechnological unit based on microbial processes to convert organic waste into protein-rich bioflocs, which act as an alternative feed source for fish and shrimp. Biofloc technology significantly reduces the feed cost by about 20 to 30 folds, enhancing the financial viability as feed accounts for 50 to 80 percent of the total production cost of the system (Avnimelech, 2012). Biofloc technology's working principle requires the continuous addition of carbon and nitrogen sources into the pond water, which acts as a stimulant for the growth of heterotrophic bacteria, which in turn fosters the production of microbial biomass. Maintenance of a carbon-to-nitrogen (C/N) ratio above 10 plays a central role to promote vigorous bacterial growth and efficient nutrient cycling within the aquaculture environment (Avnimelech, 2009; Avnimelech et al., 1999). This ratio can be achieved by the addition of carbon-rich organic sources like molasses, wheat flour and starch. Alternatively, adjusting feed protein levels downward also promotes the growth of heterotrophic bacteria essential for biofloc formation (Tasleem et al., 2024; Rind et al., 2023).

Biofloc technology is attributed to water quality enhancement and reduction in water utilization. The addition of carbon sources in water increases the proliferation of microbial biomass that utilizes waste materials present into the water and efficiently converts them into protein rich bioflocs. On the other hand, it operates with a zero water exchange principle, eliminating the need for excessive water intake. Ammonia level has been maintained at a nontoxic level through microbial conversions that eliminate the need for frequent water exchange. So Biofloc not only minimizes water intake requirements but also offers cost reduction to farmers and enhances biosecurity by reducing the entry of pathogenic organisms into the water. This approach improves overall efficiency and sustainability by ensuring a steady supply of high-quality fish juveniles, a critical component in the aquaculture process (Khanjani & Sharifinia, 2020; Emerenciano et al., 2012).

Adoption of biofloc setups for large-scale aquaculture production offers many environmental and economic benefits, particularly in coastal areas and marine settings (Khanjani & Sharifinia, 2020). By effectively managing aquaculture wastewater, which traditionally poses environmental challenges, biofloc systems replace conventional ingredients like soybean or fish meal in aquatic feed with floc compounds (Stockhausen et al., 2023). This substitution not only mitigates the environmental impacts associated with aquaculture but also enhances the sustainability of the entire production process.

The adoption of BFT has delivered impressive results in countries like India and Bangladesh. In India, BFT has been widely implemented in shrimp and tilapia farming, supported by government training programs and subsidies, which have increased productivity and export earnings (National fisheries Development board india,2021). Similarly, Bangladesh has integrated BFT into community aquaculture projects, particularly in areas with limited freshwater resources. These initiatives have boosted the productivity of high-value species like shrimp and carp, ensuring sustainable growth and increased incomes for farmers . Pakistan, however, has only recently begun experimenting with BFT. Pilot projects in Sindh and Punjab have shown promise, with improved yields and reduced costs, but large-scale adoption remains a challenge due to limited technical expertise and high setup costs (Pakistan Fisheries Development Board, 2020).

Tilapia, Carp and shrimp species are among the most commonly cultured species under biofloc systems (Crab et al., 2012). Shrimp species specifically adapted to biofloc systems include white leg shrimp (Litopenaeus vannamei) (Aguilera-Rivera et al., 2019; Xu & Pan, 2013), Kuruma shrimp (Marsupenaeus japonicas) (Duan et al., 2017), blue shrimp (Litopenaeus stylirostris) (Cardona et al., 2015; Emerenciano et al., 2012); white shrimp (Litopenaeus setiferus) (Khanjani et al., 2020), giant tiger shrimp (Penaeus monodon) (Anand et al., 2014), and pink shrimp (Farfantepenaeus duoradum) (Yu et al., 2020).

2.2. Economic Considerations of Biofloc System

Biofloc technology has emerged as a blue revolution replacing traditional aquaculture due to its significant effect on the growth rate, feed conversion ratio, specific growth rate of cultured individuals, increased survival rates, efficient water management, reduction in operational cost and alignment with the circular economy principles. These factors are crucial in shaping the overall economics and management strategies of aquaculture (Khanjani & Sharifinia, 2020).

Increased growth rate and decreased or nil mortality rate achieved through biofloc culture system are directly linked to economic outcomes. For instance, higher survival rates and faster growth rates can lead to substantial increases in profitability. Browdy et al. (2001) reported that a 20% increase in stocking density or growth rate can boost profitability by 57% and 45%, respectively. Moreover, reducing feeding costs by 20% can also have a significant positive impact on overall profitability (Rind et al., 2023).

One of the notable advantages of BFT systems is their ability to utilize bioflocs as a substitute for commercial feeds without compromising the growth or survival of aquatic species. These systems achieve higher efficiency in protein utilization compared to conventional methods, which contributes to cost savings. For example, producing one kilogram of tilapia or green tiger shrimp in BFT systems can result in a cost reduction of 10% and 33%, respectively, depending on factors such as species-specific requirements, feed costs, biofloc consumption, and carbohydrate prices (Megahed, 2010; De Schryver & Verstraete, 2009). BFT systems adoption also eliminates the need for organic and inorganic fertilizer inputs, typically offsetting the costs associated with these inputs. By maintaining zero water exchange, these systems also reduce water treatment expenses by approximately 30%. This efficiency not only shortens the cultivation period but also enhances the survival and growth rates of aquatic species compared to conventional methods. Consequently, BFT systems are increasingly recognized as sustainable approaches to aquaculture production (De Schryver et al., 2008; Khanjani & Sharifinia, 2020).

Avnimelech's (2009) reported a 20 to 30 percent reduction in feed cost under biofloc systems in comparison to traditional ones. The system's ability to reduce water usage by up to 90% further decreases management expenses, making it a cost-efficient alternative to conventional aquaculture practices. Hossam et al. (2021) compared the economic impact of traditional aquaculture and biofloc with respect to growth and protein utilization of Nile tilapia (*Oreochromis niloticus*).They reported significantly higher final body weight, specific growth rate, and feed conversion ratio of Tilapia, which were raised under biofloc setups. They also reported higher net incomes under this system, especially when supplemented with molasses and rice bran as carbon sources. 85 percent reduction in water usage was observed by them in this comparative study under biofloc ponds, as only 108-liter water per kg of fish was required according to their reported study, while 1166 liters of water per kg of fish was required under traditional aquaculture.

Bossier & Ekasari (2017) reported 8–43% increase in aquaculture productivity under biofloc setups along with the efficient reduction in water dependency. Recycling nutrients into microbial biomass, biofloc aquaculture operations can achieve substantial cost savings. McCusker et al. (2023) reported almost similar benefits of the adoption of biofloc setups. They reported a 15 to 20 percent increment in feed conversion ratios (FCR) along with a decrease in input feed cost and water use, which directly translate into financial benefits. These studies underscore the economic feasibility of BFT, particularly for small- and medium-scale farms aiming to optimize their resource utilization.

Khanjani et al. (2024) emphasized how BFT can reduce feed costs by up to 33% for shrimp and 10% for tilapia, despite the higher initial investment and energy demands. The long-term savings on feed and water management offset these upfront costs, making BFT an attractive option for sustainable aquaculture. Ravisankar et al. (2024) supported these findings, showcasing higher yields—up to 25 metric tons per hectare per crop—and improved FCRs. Their cost analyses revealed that even under less favorable scenarios, the internal rate of return (IRR) remained substantial, confirming the economic viability of BFT.

Studies focusing on nutrient efficiency also highlight BFT's economic value. Da Silva et al. (2013) reported significant increases in nitrogen and phosphorus utilization, reducing feed waste and lowering production costs. Jatobá & Lehmann (2021) demonstrated that biofloc systems consistently reduced FCR and increased survival rates, resulting in higher economic returns per crop cycle. Rani et al. (2017) further showed that microbial protein from bioflocs can replace up to 50% of fishmeal, significantly cutting feed expenses without compromising growth rates.

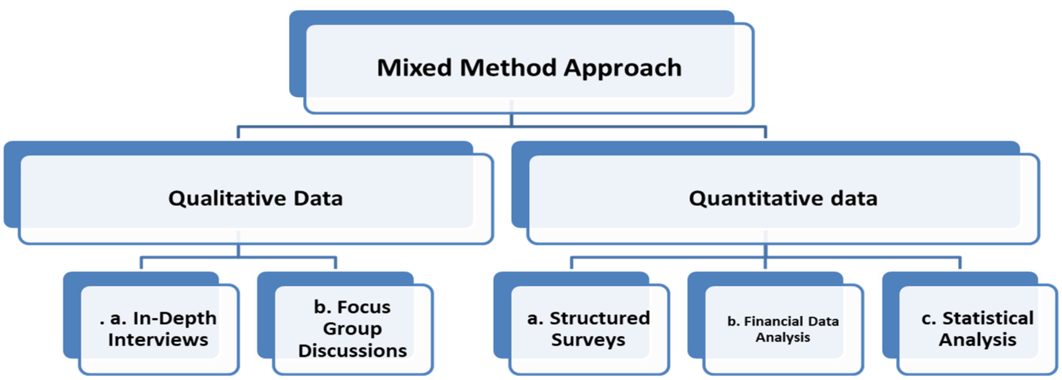
Other research has focused on the operational savings associated with BFT. Ray et al. (2010) observed that minimal water exchange in BFT systems greatly reduced pumping and treatment costs. Emerenciano et al. (2013) also emphasized that BFT's improved FCR and reduced water usage make it a financially sustainable choice. Megahed (2010) reported similar benefits, with shrimp yields increasing by 25–30% per hectare and overall operational costs decreasing due to nutrient recycling. Finally, Xu & Pan (2013) highlighted faster growth rates and better FCR among shrimp fed on bioflocs, which resulted in approximately 20% savings on feed costs.

By reducing feed and water costs, improving growth performance, and minimizing waste, BFT offers a cost-effective and sustainable solution for aquaculture operations.

RESEARCH METHODOLOGY

Large and small biofloc setups in almost all parts of Punjab, Pakistan, are part of the current project (Table 2). Faisalabad region can be considered a hub of Biofloc technology comprising hundreds of small and large private setups. Only 3 bio floc setups have been established under the Punjab Fisheries Department of Pakistan that are mainly relying on these setups for fish seed production. Out of all the biofloc setups, only one setup was running successfully by females, while all others were under the ownership of males. Both qualitative and quantitative data were collected using a semi-structured questionnaire. The questionnaire included sections on demographic information, farm characteristics, investment details, compliance with regulations, operational challenges, and growth strategies. Farmers were randomly selected from the study areas. The selection criteria ensured a diverse representation of biofloc fish farms in terms of size and operational scale. Data were collected through in-person, individual interviews conducted at the biofloc fish farming sites, typically located in outdoor areas of the farmers' houses. All interviews were conducted by trained researchers to ensure data consistency and reliability. Data related to Economic analysis was collected from biofloc set ups located at Faisalabad, Sargodha and Lahore.

Figure 2: Flow Chart of Research Methodology



3.1. Qualitative Analysis

The qualitative analysis takes into account three key approaches to have comprehensive insights into Biofloc technology. **In-depth interviews** were conducted with industry experts, aquaculture professionals, researchers, and environmental specialists using semi-structured. The data was analyzed using thematic analysis to identify common themes, benefits, challenges, and perspectives on sustainable practices. **Focus group discussions** were carried out with practitioners and stakeholders in aquaculture enterprises utilizing Biofloc technology. They shared their experiences, challenges, and strategies. Additionally, **case studies** were carried out to focus on aquaculture enterprises that have successfully implemented Biofloc technology, examining their investment journeys, compliance strategies, and growth approaches.

3.2. Quantitative Analysis

Structured surveys were conducted among a broad range of biofloc farmers utilizing Biofloc technology. These surveys included Likert scales and multiple-choice questions addressing investment patterns, cost-benefit analyses, and compliance. The collected data were analyzed using descriptive and inferential statistics to identify patterns.

Financial data analysis was performed on financial records from participating aquaculture enterprises. This involved examining investments, operational costs, and revenue streams. A comparative analysis was carried out to evaluate the economic impacts of Biofloc technology against traditional aquaculture methods.

Additionally, a **statistical analysis of growth metrics** was conducted using data such as production volume, feed conversion ratios, and market share.

Table 2: Details of Areas Visited

Location Name	Latitude	Longitude	Location Name	Latitude	Longitude
Arif Wala	30.3002	73.0669	Layyah	30.9646	70.939
Attock	33.768	72.3602	Lodhran	29.54	71.6324
Bhagtanwala	32.4	72.65	Mandi Bahauddin	32.5834	73.4844
Chakwal	32.9331	72.8586	Mian Channu	30.4467	72.3573
Dhabain	33.1667	73.1667	Multan	30.1575	71.5249
Dijkot	31.2167	73.0167	Muzaffargarh	30.0703	71.1937
Dina Jehlum	33.0167	73.6	Narowal	32.1	74.8833
Dunyapur	29.8	71.7333	Okara	30.809	73.4458
Faisalabad	31.4504	73.135	Pindigheb	33.2333	72.2667
Gujranwala	32.1877	74.1945	Rahim Yar Khan	28.4202	70.2952
Hafizabad	32.0709	73.688	Sahiwal	30.67	73.1
Hasil Pur	29.7124	72.5551	Sargodha	32.0836	72.6711
Islamabad	33.6844	73.0479	Shahkot	31.5696	73.4784
Jaranwala	31.3333	73.4333	Sheikhupura	31.7131	73.9783
Kasoor	31.115	74.4467	Sialkot	32.4927	74.5319
Kharian Gujr	32.8117	73.8655	Wah Cantt	33.7496	72.4166
Lahore	31.5204	74.3587			

Figure 3: Map of Study Area

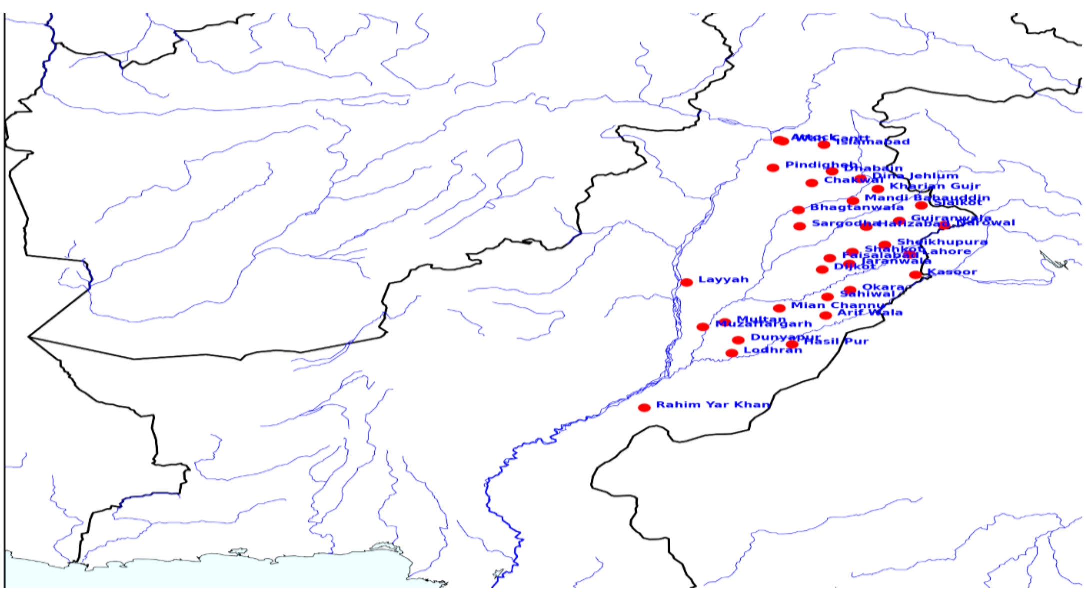


Figure 4: Study Timeline

Empowering Sustainable Aquaculture Enterprises: Unveiling the Potential of Biofloc Technology in Investments, Compliance, and Growth Strategies

(CGP-06-245)

Dr. Aima Iram Batool

Project Start: Mon, 4/15/2024

TASKS	PROGRESS	START	END
Project Initiation			
Project kickoff meeting and team assignments.	100%	04/15/24	05/15/24
Conducting a comprehensive literature review.	100%	04/15/24	06/10/24
Research instrumentation and Data Collection			
Development and design of research instruments (s	100%	04/22/24	08/30/23
Data Collection Launch.	100%	05/01/24	08/31/24
Promotion for participation, monitoring responses, a	100%	06/01/24	09/10/24
Data Collection and Analysis			
Initiate data coding and initial analysis.	100%	05/01/24	06/30/24
Commence qualitative data collection (interviews, f	100%	05/15/24	08/30/24
Qualitative Data Collection and Analysis			
Conducting interviews and focus groups.	100%	08/01/24	08/31/24
Synthesis of quantitative and qualitative data.	100%	08/01/24	09/01/24
Drafting an integrated analysis report.	100%	08/10/24	09/01/24
Report Drafting			
Writing the comprehensive research report.	100%	10/01/24	12/31/24
Review and revisions of the draft report.	100%	11/01/24	09/15/24
Finalization and Dissemination			
Final revisions and formatting of the final report.	100%	12/1/24	12/25/24
Planning for dissemination - scheduling webinars, cc	50%	12/1/24	12/16/24
Publication	50%	12//24	12/15/24

1-2 Months								3-4 Months								5-6 Month							
1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8

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FINDINGS

Based on the data collected from the 99 biofloc setups established in the key areas of Punjabis presented here.

4.1. Demographic Insights

More than fifty percent (58%) of biofloc setup owners were new to this farming technology or had less than five years of experience in biofloc farming. According to this pattern, biofloc farming is still a relatively new technology in Pakistan but is quickly becoming popular among aquaculturists, probably due to its ability to increase sustainability and fish production. Formal training based on biofloc fish farming is one of the major obstacles in setting up this technology in Pakistan. The current study identified that 60.2% of farmers lack formal training, and they rely on unofficial networks for information sharing or self-learning techniques. Meanwhile, the rest of the 39.8 percent are aware of this through attending seminars or local workshops. The lack of experience, nevertheless, might also draw attention to possible difficulties with technical know-how and proficiency, which are essential for biofloc farming to be effective.

Tilapia and Pangasius were most popular among farmers related to Biofloc culture due to their market value and adaptability to environmental factors. More than 90% of farmers preferred pangasius and tilapia for their setups. The low percentages of other species (3.1%) and ornamental fish (5.1%) suggest that farming practices are not very diverse. However, many farmers may not be able to achieve diversification at this time due to the need for greater investment, sophisticated expertise, and access to particular markets. Lack of awareness about fish species being cultured in biofloc setups globally may be the reason for relying on pangasius and tilapia.

The data on setup tanks shows that biofloc farming is primarily a small-to-medium-scale activity. Most farmers (76%) operate with 1-10 tanks, suggesting a cautious approach to investment, likely influenced by financial constraints or uncertainty about the system's profitability. The relatively low proportion of farmers with larger setups (24% for 10-20 tanks or more) reflects the need for scalability solutions and financial support for those looking to expand. Encouragingly, 42.1% of farmers are considering additional setups, indicating optimism about biofloc farming's potential.

Figure 5: Biofloc Set up

Most farmers harvest their crops once (55.1%) or twice (41.8%) per year, which could be tied to the lifecycle of the fish species or their production strategies. Frequent harvests, such as more than twice per year (3.1%), are rare and likely associated with intensive farming practices. Similarly, most farmers harvest fish in the medium-size ranges of 7-12 inches (71.6%), aligning with market preferences for medium-sized fish. Larger sizes, while fetching higher prices, require longer growing periods and higher costs, which might deter farmers from pursuing such a strategy.

The data on future plans reveals a balanced outlook. While 42.1% of farmers are optimistic and plan to install more biofloc setups, 57.9% are not considering expansion. This reluctance could stem from challenges such as high initial costs, technical barriers, or limited market access. Among those intending to expand, Tilapia (38.9%) and Pangasius (31.6%) remain the preferred species, reinforcing their dominance. Interestingly, 20.0% of farmers aim to diversify with other catfish species, signaling an interest in exploring alternatives.

Preferences for new culture systems show an even split between indoor (36.8%) and outdoor (36.8%) setups, with a significant minority (26.3%) opting for none. This reflects a diversity of strategies based on individual circumstances, such as available resources, costs, or environmental factors. Similarly, the water supply is predominantly managed through motor pumps (57.9%), with 42.1% using canal water, reflecting both mechanized and traditional methods.

Feeding strategies predominantly focus on moderate levels, with 43.2% applying 2% body weight and 35.8% using 1%. These patterns likely aim to balance growth rates with feed costs, as feed represents a significant operational expense. A smaller proportion (21.1%) opts for higher feeding rates (3%), likely aiming for faster growth or larger harvest sizes. In terms of feed brands, Hi-Tech is slightly more popular (58.9%) than Supreme (41.1%), suggesting farmer preferences based on availability, cost, or performance.

Harvesting methods show a preference for nets (61.1%), which are cost-effective and easier to manage. Water drainage (38.9%) is less common and might be used in specific setups where nets are less practical or when a complete system overhaul is planned post-harvest.

Table 3: Demographic Data Related to Biofloc

Farming experience	
less than 1 year	29 (29.3%)
less than 5 years	28 (28.3%)
less than 10 years	25 (25.3%)
less than 20 years	17 (17.2%)
Farmed fishes	
Pangasius	45 (45.5%)
Tilapia	46 (46.5%)
Ornamental fish	5 (5.1%)
Other	3 (3.0%)
Setup Tanks	
1-5 tanks	43 (43.0%)
5-10 tanks	33 (33.0%)
10-20 tanks	14 (14.0%)
more than 20	10 (10.0%)
Formal Training	

Yes	39 (39.8%)
No	59 (60.2%)
Crops per year	
1 time	54 (55.1%)
2 time	41 (41.8%)
more than 2	3 (3.1%)
More Biofloc Setup Installation	
Yes	40 (42.1%)
No	55 (57.9%)
Fishes Intended to Culture in New Set up	
Pangasius	30 (31.6%)
Tilapia	37 (38.9%)
Other Catfish	19 (20.0%)
None	9 (9.5%)
Preferred Culture System for New Set up	
indoor	35 (36.8%)
outdoor	35 (36.8%)
None	25 (26.3%)
Water Supply	
Motor Pumps	55 (57.9%)
canal water	40 (42.1%)
Average size of fish at harvest	
5-8 inch	16 (16.8%)
7-10 inch	36 (37.9%)
9-12 inch	32 (33.7%)
More than 12	11 (11.6%)
Harvesting Method	
Nets	58 (61.1%)
Water drainage	37 (38.9%)
Commonly Used Feed	
Hi-tech	56 (58.9%)
Supreme	39 (41.1%)
Feed Application	
1% body weight	34 (35.8%)
2% body weight	41 (43.2%)
3% body weight	20 (21.1%)

4.2. Thematic Analysis

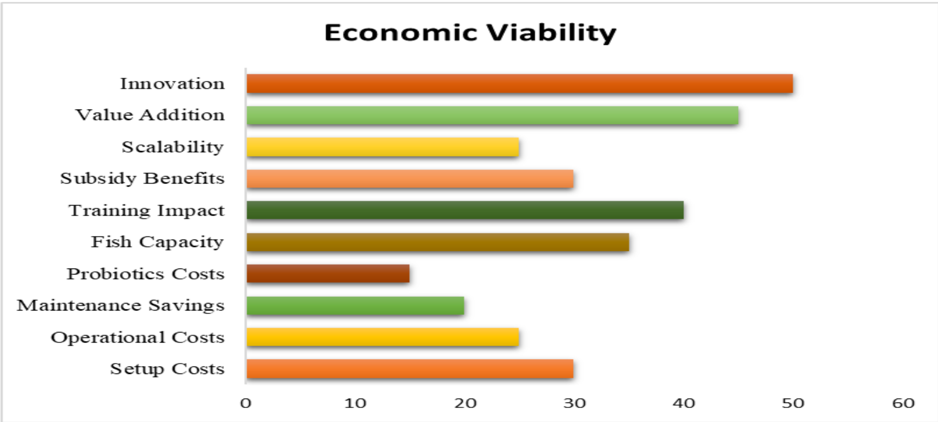
4.2.1. Economic Viability: Themes and Factors

4.2.1.1. Cost Factors

- Setup costs vary significantly by tank size and capacity.
- Higher tank capacities increase fixed costs but reduce operational costs per unit yield.
- Running costs are primarily driven by feed, water, and energy expenses.

- Maintenance costs are minimal in Biofloc systems compared to traditional systems.
- Probiotics and additives are a recurring expense unique to Biofloc.
- Initial costs for monitoring equipment are similar across systems.
- Capital investment includes tanks, aeration, and electrification for Biofloc.
- Equipment depreciation impacts long-term profitability.
- Policies like subsidies can offset initial costs.
- Scalability influences the cost per unit as systems expand.

Figure 6: Economic Viability: Key factors and their Impact



4.2.1.2. Productivity and Revenue

- Fish capacity correlates directly with tank size and efficiency.
- Seed quality affects survival rates and yield.
- Biofloc systems report higher yields per cubic meter compared to traditional systems.
- Market prices vary based on fish quality and species.
- Consistent monitoring improves production outcomes.
- Innovations like automated feeders reduce waste and increase efficiency.
- Formal training improves revenue outcomes through better practices.
- Net revenue increases with better feed conversion ratios.
- Water quality management plays a critical role in profitability.
- Value-added products (e.g., fillets) boost revenue potential.

4.2.1.3. Impact of Formal Training

- Farmers with training achieve better water quality monitoring.
- Training enhances knowledge of probiotics and additives usage.
- Operational efficiency improves with hands-on workshops.
- Networking through training programs facilitates technology transfer.
- Training in disease management reduces fish mortality.
- Awareness of market trends supports revenue growth.
- Farmers adopt innovative practices more readily after training.
- Cost-saving measures like feed optimization are introduced through training.
- Knowledge of government policies increases subsidy utilization.
- Long-term success monitoring benefits from structured training programs.

Table 4: Impact Weights for Economic Viability

Factor	Impact Weight
Setup Costs	30
Operational Costs	25
Maintenance Savings	20
Probiotics Costs	15
Fish Capacity	35
Training Impact	40
Subsidy Benefits	30
Scalability	25
Value Addition	45
Innovation	50

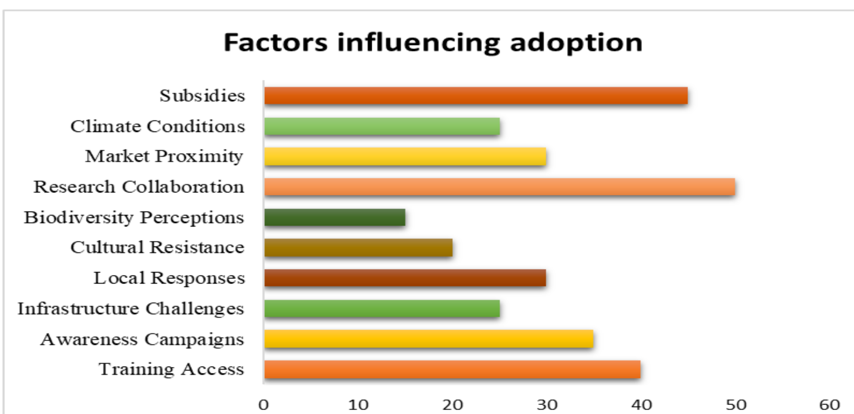
4.2.2. Factors Influencing Adoption: Themes and Factors

4.2.2.1.Knowledge and Awareness

- Lack of access to official training makes adoption more difficult.
- Campaigns for awareness increase knowledge of the advantages of Biofloc.
- There is a lack of use of online resources to learn about Biofloc.
- Insufficient knowledge about government subsidies lowers uptake. In rural locations, community networks have an impact on adoption.
- Change-averse cultures have an impact on adoption rates.

- Farms used for demonstration highlight the effectiveness of Biofloc.
- The concentration of training facilities in urban areas restricts rural farmers' access.
- One important factor in the uptake of technology is peer influence. Misconceptions regarding the complexity of Biofloc hinder its adoption.

Figure 7: Factors Influencing Adoption: Key Challenges& Enablers



4.2.2.2. Infrastructure and Regional Challenges

- Electricity costs remain a significant barrier in rural regions.
- Unstable power supply affects aeration system efficiency.
- Tank construction challenges arise in remote areas.
- Access to quality seed stock varies across regions.

- Water availability impacts scalability in arid areas.
- Biodiversity concerns vary with location and fish species.
- Lack of infrastructure for tank monitoring limits efficiency.
- Proximity to markets influences profitability.
- Regional government support affects adoption rates.
- Climate conditions impact Biofloc system performance.

4.2.2.3 Research Collaboration

- Partnerships with universities drive innovation.
- Collaborative research improves disease management practices.
- Development of cost-effective probiotics arises through research.
- Institutions promote water quality management techniques.
- Research on local fish species suitability enhances adoption.
- Studies on the long-term sustainability of Biofloc guide policy decisions.
- Joint ventures with NGOs support rural farmers.
- Collaborative pilot programs increase awareness.
- Research drives policy recommendations for Biofloc adoption.
- Collaborative platforms improve knowledge-sharing among farmers.

Table 5: Impact Weights for Factors Influencing Adoption

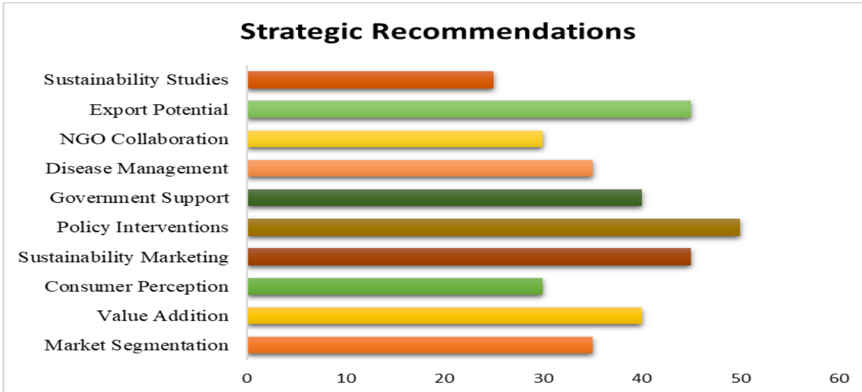
Factor	Impact Weight
Training Access	40
Awareness Campaigns	35
Infrastructure Challenges	25
Local Responses	30
Cultural Resistance	20
Biodiversity Perceptions	15
Research Collaboration	50
Market Proximity	30
Climate Conditions	25
Subsidies	45

4.2.3. Strategic Recommendations: Themes and Factors

4.2.3.1 Market and Consumer Insights

- Market segmentation for Biofloc products increases profitability.
- Value addition (e.g., processed fish) improves market appeal.
- Consumer perceptions of sustainable practices are positive.
- Marketing campaigns emphasize Biofloc’s environmental benefits.
- Partnerships with retail chains boost product visibility.
- Negative consumer perceptions highlight the need for awareness campaigns.
- Certification programs for Biofloc farms increase trust.
- Quality assurance practices enhance consumer confidence.
- Export potential for Biofloc products increases revenue streams.
- Integration of e-commerce platforms expands market reach.

Figure 8: Strategic Recommendations: Key Area for Growth



4.2.3.2 Policy and Sustainability

- Electricity subsidies encourage wider adoption.
- Tax exemptions for sustainable practices incentivize farmers.
- Long-term government policies promote investment in Biofloc.
- Sustainability programs ensure resource optimization.
- Disease management strategies improve system efficiency.
- Feed optimization research enhances profitability.
- Policies promoting renewable energy reduce operational costs.
- Training programs supported by governments increase uptake.
- Collaboration with NGOs supports underprivileged farmers.
- Regional sustainability studies guide resource allocation.

Table 6: Impact Weights for Strategic Recommendations

Factor	Impact Weight
Market Segmentation	35
Value Addition	40
Consumer Perception	30
Sustainability Marketing	45
Policy Interventions	50
Government Support	40
Disease Management	35
NGO Collaboration	30
Export Potential	45
Sustainability Studies	25

4.2.4. Factors Influencing Biofloc Adoption Success: Thematic Analysis

4.2.4.1. High Importance Factors: Key Findings

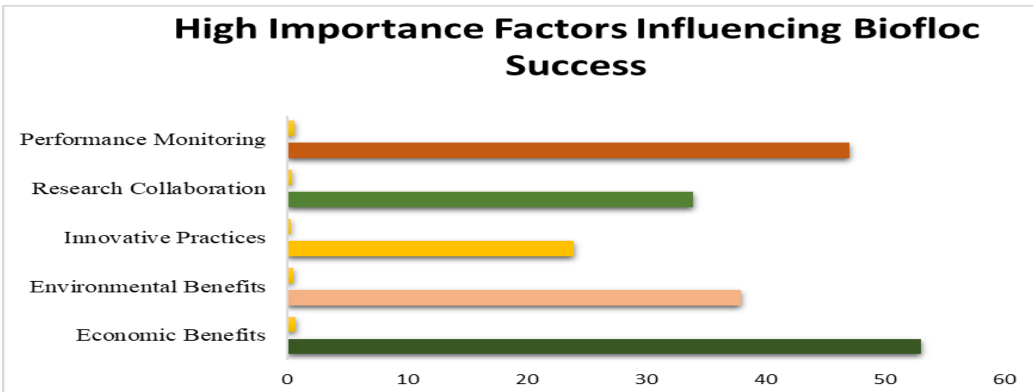
1. **Economic Benefits** (e.g., reduced feed costs, increased profitability).
2. **Innovative Practices** (e.g., photoperiod manipulation, automated feeding systems,).
3. **Environmental Benefits** (e.g., reduced water usage, improved water quality).

4. **Performance Monitoring** (e.g., fish growth, water quality,)
5. **Research Collaboration** (e.g., partnerships with universities or experts).

Table 7: High Importance Factors

Factor	Frequency	Percentage
Economic Benefits	53	71.6%
Environmental Benefits	38	51.4%
Innovative Practices	24	32.4%
Research Collaboration	34	45.9%
Performance Monitoring	47	63.5%

Figure 9: High Importance Factors Influencing Biofloc Success



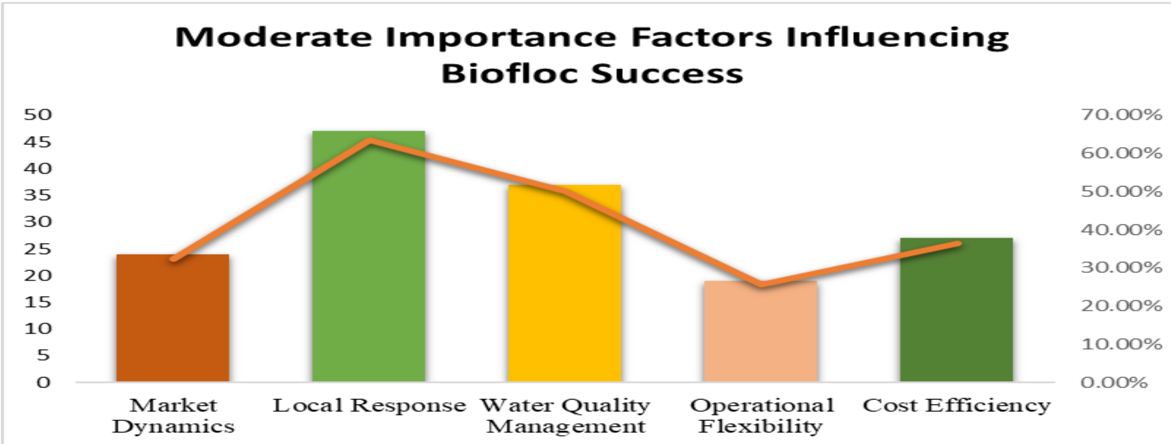
4.2.4.2. Moderate Importance Factors: Key Findings

1. **Operational Flexibility** (e.g., ease of adoption processes).
2. **Market Dynamics** (e.g., value addition, collaborations).
3. **Water Quality Management** (e.g., satisfied users reporting stability).
4. **Local Response** (e.g., positive feedback, local acceptance).
5. **Cost Efficiency** (e.g., decreasing operational costs).

Table 8: Moderate Importance Factors

Factor	Frequency	Percentage
Market Dynamics	24	32.4%
Local Response	47	63.5%
Water Quality Management	37	50.0%
Operational Flexibility	19	25.7%
Cost Efficiency	27	36.5%

Figure 10: Moderate Importance Factors Influencing Biofloc Success



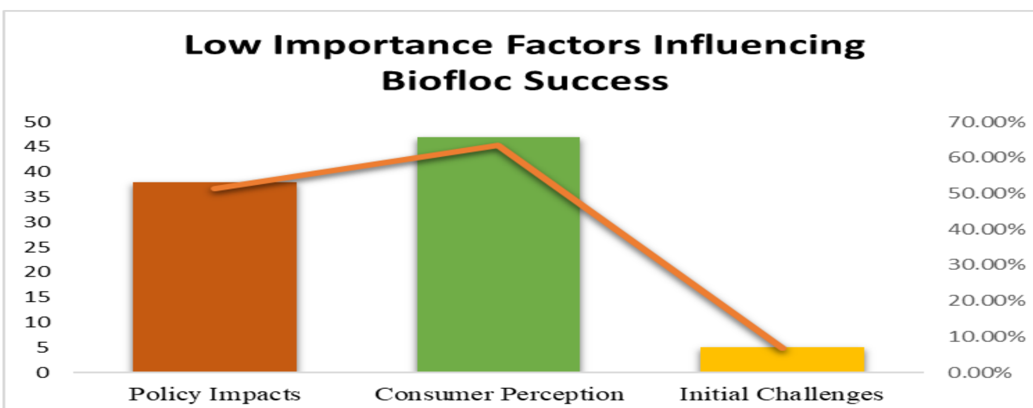
4.2.4.3. Low Importance or Emerging Factors: Key Findings

1. **Policy Impacts** (e.g., electricity costs, tax issues).
2. **Consumer Perception** (e.g., varying attitudes toward biofloc products).
3. **Initial Challenges** (e.g., technical hurdles, cost of setup).

Table 9: Low Importance or Emerging Factors

Factor	Frequency	Percentage
Policy Impacts	38	51.4%
Consumer Perception	47	63.5%
Initial Challenges	5	6.8%

Figure 11: Low Importance Factors Influencing Biofloc Success



4.2.5. Challenges Influencing Biofloc Adoption: Thematic Analysis

4.2.5.1. High Importance Challenges: Key Findings

1. **Policy Impacts**: Issues like electricity costs and taxation were frequently mentioned.
2. **Consumer Perception**: Mixed or negative consumer attitudes present a significant hurdle.
3. **Initial Challenges:** Start-up complexities such as training gaps and high costs.
4. **Technical Barriers**: Problems with technical adoption and operational inefficiencies.

5. **Operational Costs**: Rising costs in setup and maintenance impact adoption rates.

Figure 12: High Importance Challenges Influencing Biofloc Adoption

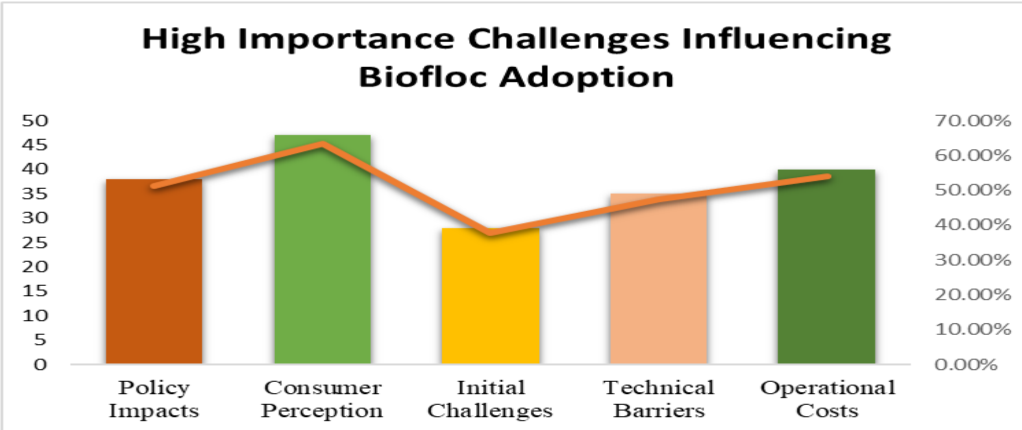


Table 10: High Importance Challenges

Factor	Frequency	Percentage
Policy Impacts	38	51.4%
Consumer Perception	47	63.5%
Initial Challenges	28	37.8%
Technical Barriers	35	47.3%
Operational Costs	40	54.1%

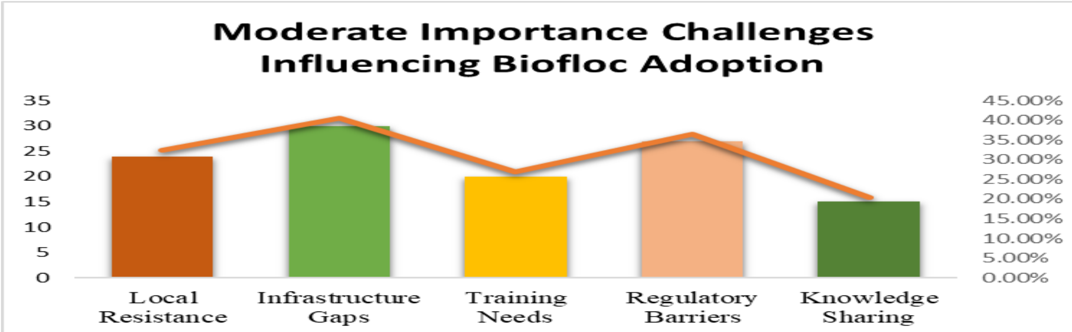
4.2.5.2. Moderate Importance Challenges: Key Findings

1. **Local Resistance**: Hesitation or opposition from local communities.
2. **Infrastructure Gaps**: Limited infrastructure to support adoption.
3. **Lack of formal training:** Lack of training for biofloc farmers and stakeholders.
4. **Lack of Awareness of Regulatory Policies:** Challenges with compliance and policy clarity.
5. **Exchange of Information among biofloc setup holders**: Limited dissemination of best practices**.**

Table 11: Moderate Importance Challenges

Factor	Frequency	Percentage
Local Resistance	24	32.4%
Infrastructure Gaps	30	40.5%
Training Needs	20	27.0%
Regulatory Barriers	27	36.5%
Knowledge Sharing	15	20.3%

Figure 13: Moderate Importance Challenges Influencing Biofloc Adoption



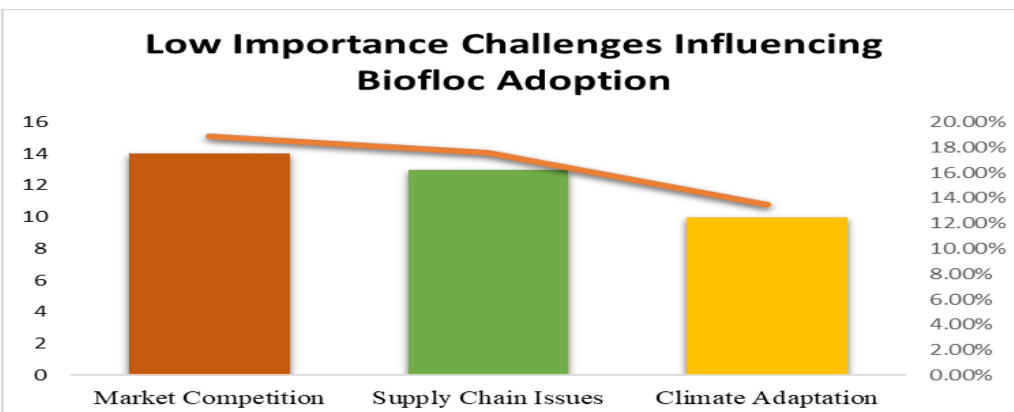
4.2.5.3. Low Importance or Emerging Challenges: Key Findings

1. **Market Competition for Alternative to Biofloc**: Pressure from competitors adopting alternative technologies.
2. **Supply Chain Issues**: Difficulty in accessing reliable inputs.
3. **Climatic Issues**: Environmental changes affecting biofloc operations.

Table 12: Low Importance or Emerging Challenges

Factor	Frequency	Percentage
Market Competition	14	18.9%
Supply Chain Issues	13	17.6%
Climate Adaptation	10	13.5%

Figure 14: Low Importance Challenges Influencing Biofloc Adoption



4.3. Economic Analysis of Traditional Pond System (1 acre) and Biofloc Tank System (4 tanks/acre)

There are notable distinctions in infrastructure and working needs between Biofloc Technology and traditional Aquaculture when comparing fixed and operating costs (Table 13). Although Biofloc Technology has higher initial fixed costs (PKR 1,750,000) as compared to traditional aquaculture set ups(PKR 12,000,000) as well as it requires specialized equipment such as aerators (PKR 100,000) and PVC pipe fittings (PKR 80,000) for efficient oxygen and water management but the running costs per crop are significantly lower in Biofloc Technology (PKR 66,000), which uses probiotics and efficient feed conversion ratios. Running cost is significantly higher in Traditional Aquaculture (PKR

175,000) due to larger water and feed requirements. Biofloc Technology offers long-term benefits despite increased initial setup investment, including lower running costs, reduced use of land, feed& labor and good control over water quality parameters, making it a more efficient and sustainable substitute to Traditional Aquaculture.

Table 13: Fixed Capital Costs

Sr. No.	Component	Traditional Aquaculture (PKR)	Biofloc Technology (PKR) 4 tanks/acre
1.	Setup of Tanks/Ponds	250,000	520,000/acre
2.	Shed Material	No Need	40,000
3.	Water Supply (Borewell)	250,000	100,000
4.	PVC Pipe Fittings	0	80,000
5.	Nets and Accessories	50,000	10,000
6.	Blower, Air Stones, Aeration Equipment	No Need	100,000
7.	Electrification	5,000,000	200,000
8.	Power Generator	No Need	100,000
9.	Monitoring Equipment (Weighing Scale, pH Meter, DO Meter)	500,000	500,000
10.	Miscellaneous Expenses	100,000	100,000
Total Fixed Cost		1,200,000	1,750,000
Input Cost for One crop(Running Cost)			
Seed cost, Feed cost, Probiotics, Test kits etc.		175,000	66,000
Total Cost		1,375,000	1,816,000

Source: Bismillah Biofloc , Afnan Farms, Saeed Farms, Chattha Farms.

Comparative analysis of operational costs for Biofloc Technology and Traditional Aquaculture reveals notable differences in operating expenses, providing insight into the latter's effectiveness and cost-effectiveness. One key distinction is the cost of feed, with traditional aquaculture requiring much greater expenditures (between PKR 40,000 and PKR 80,000 for each crop) (Table 14). Low effectiveness in feed conversion ratios is one of the marked differences that makes Traditional aquaculture inferior than biofloc technology. As a result of its optimized nutrient usage and decreased waste, Biofloc Technology, on the other hand, is able to maintain feed costs at an exceptionally low level, at only PKR 14,000 to PKR 17,000 per crop. However, compared to Traditional Aquaculture (PKR 10,000), Biofloc systems have higher seed prices (PKR 30,000). The use of better seed stock or greater amounts required to reach the required stocking densities in Biofloc systems is the reason behind this. Despite this discrepancy, the advantages of better fish health and increased survival rates frequently outweigh the extra cost of seeds. With yearly costs of only PKR 12,000, much less than the PKR 55,000 needed for traditional aquaculture, water costs further highlight the effectiveness of Biofloc Technology. This sharp contrast results from the smaller water quantities used in Biofloc systems, where microbiological activities guarantee constantly stable water quality. Furthermore, at PKR, traditional aquaculture has ongoing expenses for carbon sources and probiotics.

Another area of differentiation is maintenance costs. Because of its creative design and low infrastructure wear, Biofloc Technology completely eliminates the maintenance costs associated with traditional aquaculture, which require an additional PKR 25,000 for every crop. Due to the labor-intensive nature of pond care, traditional aquaculture charges PKR 20,000 per acre, while

Biofloc systems, which rely on automated processes and simplified operations, only charge PKR 5,000 per acre. The cost of the monitoring equipment is the sole operational expense equivalence, staying at PKR 25,000 for both systems. In contrast to Biofloc Technology, which requires PKR 66,000, Traditional Aquaculture's entire operating costs, when added up, exceed PKR 175,000 for each crop.

Table 14: Running Cost

Sr. No.	Particulars	Traditional Aquaculture (PKR)	Biofloc Technology (PKR)
	Feed Costs	40,000-80,000	14,000-17,000
	Seed @Rs.10/	10,000	30,000
	Water Cost	55,000/year	10,000/year
	Probiotics and Carbon Sources	-	2,500/crop
	Maintenance Costs	25,000	2,000
	Labor Costs	20,000/acre	5,000/acre
	Monitoring Equipment Usage	25,000	25,000
Total Running Costs		175,000	66,000

Both noteworthy and indicative of their divergent operating efficiencies is the difference in fish productivity and revenue creation between Biofloc Technology and Traditional Aquaculture. In traditional aquaculture, there are only two to five fish per cubic meter, or roughly 1,000 fish overall, which is a rather low stocking density. The poor yield of 0.5 kilos per cubic meter, which is the result of this limited capacity, leads to a yearly production of 1,000 kilograms of fish. On the other hand, Biofloc Technology uses its sophisticated system design to support 3,000 fish at a significantly greater stocking density of 25–40 fish per cubic meter (Table 15).

Due to their improved quality and increased market demand, fish raised in these systems fetch a premium price of PKR 400–700 per kilogram, further favoring Biofloc Technology in the market dynamics. On the other hand, fish from traditional aquaculture sell for between PKR 300 and 550 per kilogram, which suggests a quality discrepancy that reduces potential earnings.

Gross revenue is drastically different as a result of this disparity in pricing and production. The gross earnings from traditional aquaculture ranges from PKR 300,000 to PKR 550,000 per year. Comparatively speaking, Biofloc Technology generates a substantially larger gross revenue range of PKR 1,200,000–2,100,000, demonstrating its capacity to optimize profits through better product quality and effective resource usage. Feed costs serve as another example of how the two systems differ in terms of economic efficiency. Due to less effective feed conversion ratios, traditional aquaculture incurs feed expenditures of about PK 80,000 per year; however, Biofloc Technology significantly lowers these costs to just PKR 17,000. This decrease guarantees that Biofloc systems are significantly more economical when paired with increased yields. Traditional Aquaculture’s net revenue is limited to PKR 220000-470000 annually, whereas Biofloc Technology delivers a remarkable net revenue range of PKR 1183000-2083000. This substantial financial advantage underscores the value of Biofloc Technology as a transformative approach to aquaculture.

Table 15: Yield of Fish

Sr. No.	Parameter	Traditional Aquaculture (PKR)	Biofloc Technology (PKR)

1.	Stocking Density (fish/m^3)/number of fish	2-5/m3/1,000 fishes	25-40 /m3/3,000
2.	Yield per m^3 (kg)	0.5 kg/m3/1 ton	20kg/m3
3.	Annual Yield (kg)	1,000 kg	3,000kg
4.	Sale Price per kg (PKR)	300-550/kg	400-700/kg
5.	Gross Revenue (PKR)	300,000-550,000	1,200,000-2,100,000
6.	Feed Cost (PKR)	80,000	17,000
7.	Net Revenue (PKR)	220,000-470,000	1,183,000-2,083,000

The economic feasibility analysis reveals that Biofloc Technology is significantly more profitable and sustainable than traditional aquaculture after two production cycles. Although Biofloc Technology requires a higher initial capital investment of PKR 1,750,000 compared to Traditional Aquaculture's PKR 1,200,000, it benefits from much lower running costs of PKR 66,000 per crop compared to PKR 175,000 for Traditional Aquaculture. As a result, the total cost for Biofloc (PKR 1,816,000) remains manageable, especially when contrasted with its higher gross income of PKR 1,200,000–2,100,000 per crop, far exceeding Traditional Aquaculture's gross income of PKR 300,000–550,000 per crop. At the end of one crop, after deducting the recurring costs for the second crop, Biofloc generates a gross income of PKR 1,134,000–2,034,000 compared to Traditional Aquaculture's PKR 125,000–375,000. By the end of two crops, Biofloc accumulates a gross income of PKR 2,334,000–4,134,000, compared to Traditional Aquaculture's PKR 425,000–925,000, its operational efficiency ensures a recurring cost of only PKR 66,000 per crop, compared to PKR 175,000 for Traditional Aquaculture. Ultimately, after two crops, Traditional Aquaculture gets a net profit of approximately PKR 250000-750000 while Biofloc Technology achieves a net profit of PKR 2268000-4068000, highlighting its superior economic feasibility and profitability (Table 16).

Table 16: Economic Feasibility

	Components	Traditional Pond	Biofloc
1	Capital Cost	1,200,000	1,750,000
2	Running Cost	175,000	66,000
3	Total Cost	1,375,000	1,816,000
4	Gross income per crop	300,000-550,000	1,200,000-2,100,000
5	Gross income at the end of one crop after deducting the recurring cost for the 2nd crop	125,000-375,000	1,134,000-2,034,000
6	Gross income from the 2nd crop	300,000-550,000	1200000-2100000
7	Gross income at the end of 2nd crop	425,000-925,000	2,334,000-4,134,000
8	Recurring cost for the next crop	175,000	66,000
9	Net profit at the end of 2nd crop	250,000-750,000	2,268,000-4,068,000

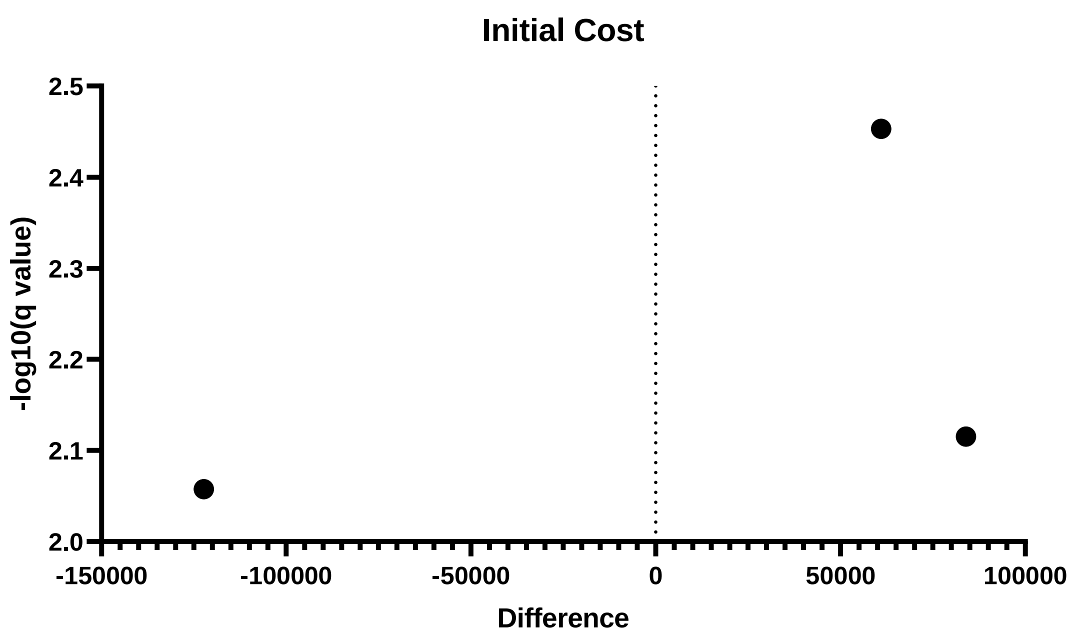
4.3.1. Initial Cost of Biofloc and Pond Aquaculture System

The paired t-test analysis compares the costs of biofloc and traditional pond aquaculture systems in Pakistani Rupees (PKR), highlighting significant differences across various cost components. For the initial cost (Table 17 and Figure 15), constructing a tank for the biofloc system averages PKR 520000, which is substantially higher than the PKR 250000 required for a pond in the traditional system, with a significant difference of PKR 270000. This indicates that traditional systems are more cost-efficient in terms of infrastructure setup. However, the water supply system for traditional ponds costs PKR 250000, significantly exceeding the PKR 100000 required for the biofloc system, resulting in a notable saving of PKR 150000 in favor of biofloc. Similarly, water aeration equipment, unique to the biofloc system, requires an investment of PKR 100000, whereas traditional systems incur no such expense. This additional cost for biofloc, though significant, highlights its need for advanced water management.

Table 17: Comparison of the Initial Cost for Biofloc and Traditional Pond Aquaculture System

Factors	P value	Mean of Biofloc System	Mean of Traditional Pond System	Difference	SE of difference	t ratio	df
Tank (80,000 liter size) pond (1 Acre) construction	0.005	520,000	250,000	270,000	1,977.14450	136.567	28.000
Water supply	0.008	100,000	250,000	-150,000	3.17490	-47245.559	28.000
Water aeration equipment	0.001	100,000	0.000	100,000	1,046.79626	95.652	28.000

Figure 15: Volcano Graph Showing the Initial Cost Analysis for the Biofloc and Traditional Pond Aquaculture



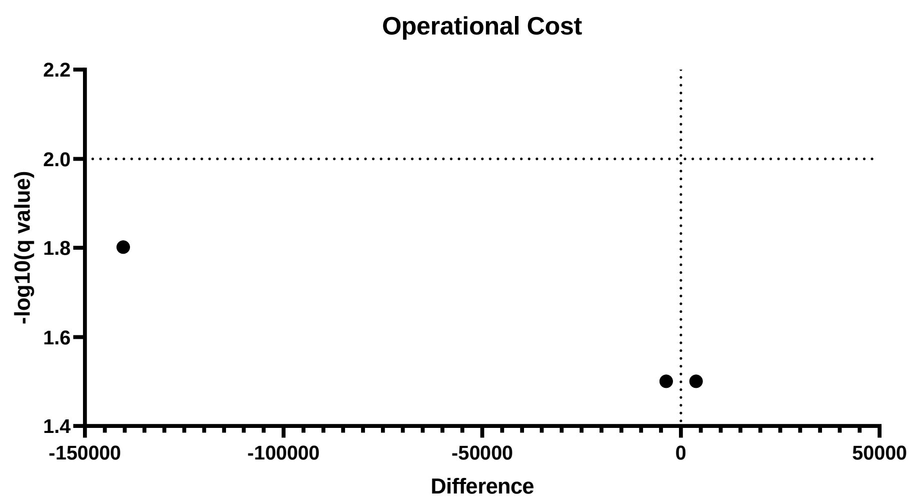
4.3.2. Operational Cost of Biofloc and Pond Aquaculture System

Operational cost results are given in the Table 18 and Figure 16. Results show a different trend. Feed costs in biofloc systems average PKR 17000, significantly lower than the PKR 80000 required in traditional systems, showing savings of PKR 63000 and reflecting better feed efficiency in biofloc. Both systems have identical costs for Monitoring Equipment Usage at PKR 25000, showing no difference in this aspect. However, water costs are markedly lower in biofloc systems at PKR 10000 compared to PKR 55000 for traditional systems, saving PKR 40000. Probiotics and additives, unique to biofloc systems, cost PKR 2500, which is an additional expense not incurred by traditional systems but necessary for maintaining water quality in biofloc setups. Finally, labor costs in traditional systems are significantly higher at PKR 20000 compared to PKR 5000 in biofloc systems, offering a saving of PKR 15000. Overall, the analysis shows that while biofloc systems demand higher initial investments, particularly for water filtration and tank construction, they significantly reduce operational costs, including feed, labor, and maintenance. Traditional systems are less expensive to establish but incur higher ongoing expenses, making biofloc systems potentially more economical in the long term despite the additional initial costs. The results underline the trade-offs between these systems, with biofloc offering advanced technology and efficiency at a premium, whereas traditional systems provide a simpler, more cost-effective entry point with higher recurring costs.

Table 18: Comparison of the Operational Cost for Biofloc and Traditional Pond Aquaculture System

Factors	P value	Mean of Biofloc System	Mean of Traditional Pond System	Difference	SE of difference	t ratio	df
Feed cost	0.005212	17,000	80,000	-63000	60.14439	-1,048.991	28.000
Solar system Installatio n		25,000	25,000	0.000	0.000		
Water Cost	0.031279	10,000	55,000	-45000	20.91	-2,150.839	28.000
Probiotics and additives	0.023704	2,500	0.000	2500	4.24	588.63	28.000
Labor		5,000	20,000	-15000	4.98	-3,012.121	28

Figure 16: Volcano Graph Showing the Operational Cost Analysis for the Biofloc and Traditional Pond Aquaculture



4.3.3. Emergy Synthesis

The emergy synthesis of a system includes determining the research boundaries, organization of input and output data, determining the emergy baseline, calculating the emergy flow and the emergy indicators. Emergy indicators are valuable tools for measuring the ecological and sustainable performance of the system being evaluated.

Table 19: The Emergy Analysis Comparing Traditional Aquaculture and Biofloc Technology

System	Fixed Costs (PKR)	Running Costs (PKR)	Total Cost (PKR)	Fish Yield (kg)	Emergy Input (seJ)	Emergy Output (seJ)	EYR	ELR (Assumed)	SI
Traditional Aquaculture	1,200,000	175,000	1,375,000	1,000	6.875E+12	3,500,000,000	0.0005 09091	2.5	0.000203 636
Biofloc Technology	1,750,000	66,000	1,816,000	3,000	9.08E+12	10,500,000,000	0.0011 56388	1.5	0.000770 925

Efficiency, sustainability, and environmental impact all differ significantly between Biofloc Technology and Traditional Aquaculture, according to the emergy study. Traditional aquaculture yields 1,000 kg of fish a year, with fixed expenses of PKR 1,200,000 and operating costs of PKR 175,000. This results in an Environmental Loading Ratio (ELR) of 2.5, a Sustainability Index (SI) of 0.000204, and an Emergy Yield Ratio (EYR) of 0.000509. On the other hand, Biofloc Technology achieves a significantly larger production of 3,000 kg per year with running expenses of only PKR 66,000, although having higher fixed costs of PKR 1,750,000. With a more favorable EYR of 0.001156, an ELR of 1.5, and a SI of 0.000771, this system stands out for its increased sustainability, less dependency on non-renewable resources, and increased efficiency.

CONCLUSION

A ground-breaking answer to the problems facing conventional aquaculture is biofloc technology. It is a revolutionary method for sustainable food production because of its capacity to increase output, preserve land and water resources, and produce significant financial rewards. According to this study, biofloc systems have a number of benefits over traditional techniques, such as up to three times greater production and a 60% lower operating cost. Additionally, biofloc's advantages for the environment—such as lower effluent discharge and effective resource use—make it a major force behind sustainable aquaculture.

Numerous obstacles hinder the widespread use of biofloc technology, despite its potential. Significant obstacles include high upfront investment costs, a lack of technical know-how, constrictive legislative frameworks, and inadequate training availability. These difficulties show that in order to promote and expand the usage of biofloc systems, targeted measures are required. By resolving these problems, aquaculture businesses will be able to make full use of this cutting-edge technology, promoting both economic expansion and sustainable development.
This study emphasizes how crucial it is for researchers, industry stakeholders, and legislators to work together to remove current obstacles. Collaboration and biofloc system investments can help the aquaculture industry shift to more profitable, efficient, and sustainable methods.

POLICY RECOMMENDATIONS

1. Financial Support:
    - Implement grants or subsidies to lessen the financial strain of the large upfront expenses related to biofloc setups.
    - Offer financing alternatives or low-interest loans specifically designed for small and medium-sized farms.
    - To promote sustainable practices, provide tax incentives to farmers and businesses who implement biofloc systems.
2. Capacity Building:
    - Create thorough training programs that concentrate on the technical facets of biofloc technology, including feed optimization, illness prevention, and water quality control.
    - Create certification programs to verify farmers' proficiency in biofloc operations and boost consumer confidence.
    - Establish demonstration farms to promote broader use and highlight the useful advantages of biofloc systems.
3. Infrastructure Development:
    - Improve access to dependable energy sources, including renewable energy solutions, to support the ventilation needs of biofloc systems.
    - Invest in rural substructure to facilitate transport and access to markets for biofloc-raised products.
    - Ensure the accessibility of high-quality seed stock, feed, and probiotics to recover the efficiency of biofloc operations.
4. Regulatory Reforms:
    - Develop region-specific guidelines to address local challenges, such as water availability and climate conditions.
    - Simplify regulatory procedures to make it easier for farmers to comply with environmental and operational requirements.
    - Renewable energy technologies should be promoted through supportive policies and incentives.
5. Market Development:
    - Fish consumers should be educated through social media, news channels and local seminars, about ecological and health benefits of biofloc farm raised fishes as compared to traditional ones.
    - Eco-labeling and certification programs should be launched to improve the marketability and consumer trust in biofloc products.

6. Research and Collaboration:
    - Collaboration between academia, industry and government needs to be strengthened in order to address technical issues in biofloc systems.
    - Longitudinal studies are required on scalability and sustainability of biofloc setups under varying environmental and geographical conditions.
7. Public-Private Partnerships:
    - Collaborate with non-governmental organizations to provide technical support and resources for disadvantaged farmers.
    - Foster joint ventures between government bodies and private organizations to fund and promote biofloc acceptance.

These recommendations aim to discourse the economic, technical, and controlling barriers hindering the adoption of biofloc knowhow**.**

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