Published by University of Muhammadiyah Makassar

DOI: 10.26618

e-ISSN 2686-5467 | p-ISSN 1858-2192

Balance: Jurnal Ekonomi

journal homepage: https://journal.unismuh.ac.id/index.php/jeb

Strengthening Community-Based Tilapia Aquaculture Through Biofloc Technology: Evidence from Paccerakkang, Makassar, Indonesia

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ARTICLE INFO

Biofloc technology; community empowerment; tilapia aquaculture; Asset-Based Community Development (ABCD); sustainable aquaculture.

Article History

- Received: 15 December 2025
- First Revision: 20 February 2026
- Second Revision: 05 April 2026
- Third Revision: 10 May 2026
- Accepted: 30 May 2026

ABSTRACT

Biofloc technology has emerged as a sustainable aquaculture innovation capable of improving production efficiency while minimizing environmental impacts, making it particularly suitable for small-scale fish farming in areas with limited land and water resources. However, its adoption among community-based tilapia farmers remains constrained by limited technical knowledge, inadequate managerial skills, and insufficient extension support. This study aims to evaluate the implementation of a community empowerment program based on the Asset-Based Community Development (ABCD) approach to strengthen farmers' capacity in adopting biofloc-based tilapia farming in Paccerakkang Sub-district, Makassar City, Indonesia. A community-based participatory research design combining qualitative and quantitative approaches was employed. Data were collected through field observations, semi-structured interviews, questionnaires, and documentation during four implementation stages: asset identification, technical training, field mentoring, and program evaluation. The findings indicate that the intervention significantly improved participants' knowledge and practical skills in pond preparation, biofloc formation, water quality management, feeding strategies, disease prevention, harvesting techniques, and simple financial record-keeping. Participants also demonstrated greater readiness to implement environmentally sustainable aquaculture practices while recognizing the economic potential of biofloc technology in improving production efficiency and household income. Continuous mentoring further strengthened farmers' managerial competencies and enhanced confidence in adopting innovative cultivation techniques. The study concludes that integrating biofloc technology with participatory community empowerment effectively supports sustainable aquaculture development by increasing farmers' technical capacity, operational efficiency, and business competitiveness. These findings provide practical recommendations for fisheries extension programs and policymakers seeking to promote resilient, environmentally friendly, and community-based freshwater aquaculture in Indonesia.

1. Introduction

Aquaculture has become one of the fastest-growing food production sectors worldwide, contributing significantly to food security, employment, and rural economic development. Among freshwater commodities, Nile tilapia (*Oreochromis niloticus*) is one of the most widely cultivated fish due to its rapid growth, high adaptability to environmental changes, and strong market demand. However, increasing production while maintaining environmental sustainability remains a major challenge, particularly for small-scale fish

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farmers operating with limited resources and technical knowledge.

In Indonesia, many community-based aquaculture activities are managed by smallholder farmers whose primary occupations often generate unstable incomes. As a result, fish farming has become an important alternative source of household income. In Paccerakkang Sub-district, Makassar City, South Sulawesi, tilapia farming represents a promising economic activity because of the increasing consumer demand for freshwater fish. Nevertheless, most local farmers continue to employ conventional cultivation methods characterized by low productivity, inefficient feed utilization, poor water quality management, and limited adoption of modern aquaculture technologies. These constraints reduce production efficiency and limit farmers' capacity to improve their household incomes.

One technological innovation that has attracted considerable attention in sustainable aquaculture is the biofloc system. Biofloc technology utilizes beneficial microorganisms, including bacteria, algae, fungi, and plankton, to convert organic waste and inorganic nitrogen compounds into microbial biomass that can be consumed by fish as an additional protein source. Consequently, this system improves feed conversion efficiency, enhances water quality, reduces water exchange requirements, and minimizes environmental pollution while increasing fish production (Ombong & Salindeho, 2016). Previous studies have demonstrated that biofloc technology can significantly improve tilapia growth performance, survival rates, and production efficiency when supported by appropriate management practices (Adibrata et al., 2021; Munaeni et al., 2022).

Despite these advantages, the successful implementation of biofloc technology requires adequate technical knowledge and continuous monitoring of several critical water quality parameters, including dissolved oxygen, pH, nitrate concentration, and biofloc density. Aeration systems must operate continuously to maintain sufficient oxygen availability for microbial metabolism, while excessive or insufficient floc density requires regular adjustment through siphoning, dilution, or probiotic supplementation. Inadequate management of these factors may reduce fish growth, increase disease susceptibility, and ultimately decrease production performance. Unfortunately, many small-scale farmers have not yet acquired sufficient knowledge or practical skills to operate biofloc systems effectively.

Previous community development programs have primarily focused on introducing biofloc technology without comprehensively integrating farmer capacity building in feed formulation, disease prevention using environmentally friendly materials, financial management, and routine monitoring of culture systems. Consequently, a substantial knowledge and implementation gap remains between technological innovations and their practical adoption at the community level. Strengthening farmers' competencies through integrated education and technical assistance is therefore essential to maximize the benefits of biofloc technology and promote sustainable aquaculture development.

From the perspective of rural economic development, improving farmers' technical capabilities is closely associated with increased productivity, production efficiency, and household income. Human resource development through participatory training and extension programs has been recognized as an effective strategy for accelerating technology adoption and improving the sustainability of community-based aquaculture enterprises (Ibrahim, 2023; Ibrahim & Achmad, 2024). Therefore, extension activities should not only transfer technical knowledge but also develop managerial competencies that enable farmers to operate aquaculture businesses more efficiently and competitively.

Based on these considerations, this study aims to evaluate the implementation of training and extension programs on biofloc-based tilapia farming for community groups in

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Paccerakkang Sub-district, Makassar City. Specifically, the study examines how integrated capacity-building activities—including technical training on biofloc management, feed production, fish health management, water quality control, and simple financial management—can enhance farmers' knowledge, practical skills, and production capacity. The findings are expected to provide practical recommendations for community empowerment programs and contribute to the broader implementation of sustainable aquaculture technologies in Indonesia.

2. Literature Review

2.1. Biofloc-Based Tilapia Farming

Biofloc technology (BFT) has emerged as one of the most sustainable innovations in modern aquaculture because it simultaneously improves production efficiency and environmental sustainability. The technology is designed to convert organic waste, uneaten feed, and fish excreta into microbial biomass through the activity of heterotrophic microorganisms. By increasing the carbon-to-nitrogen (C/N) ratio, heterotrophic bacteria assimilate inorganic nitrogen compounds, particularly ammonia, into microbial protein that can subsequently be utilized as an additional natural feed source for cultured fish. Consequently, biofloc technology not only reduces water pollution but also enhances feed efficiency and lowers operational costs.

The effectiveness of biofloc systems depends on the establishment of a balanced microbial ecosystem consisting of bacteria, algae, fungi, protozoa, and other beneficial microorganisms. These organisms aggregate into suspended flocs that continuously recycle nutrients within the culture environment. The formation of biofloc requires four essential components: sufficient organic matter, an appropriate carbon source, active heterotrophic bacteria, and continuous oxygen availability. Aeration plays a crucial role by maintaining dissolved oxygen levels, keeping flocs suspended, and supporting microbial metabolism. Therefore, biofloc ponds generally require uninterrupted aeration throughout the cultivation period.

Several studies have demonstrated that biofloc technology significantly improves water quality by reducing ammonia accumulation, stabilizing pH, minimizing water exchange, and increasing fish survival and growth performance. Compared with conventional aquaculture systems, biofloc-based cultivation provides higher stocking densities while maintaining environmental quality and reducing feed conversion ratios. These advantages make the technology particularly suitable for small-scale aquaculture where land and water resources are limited (Ombong & Salindeho, 2016; Adibrata et al., 2021).

Nile tilapia (*Oreochromis niloticus*) is considered one of the most suitable species for biofloc cultivation because of its high tolerance to fluctuating environmental conditions and its ability to efficiently utilize microbial flocs as supplementary nutrition. Nevertheless, successful implementation requires continuous monitoring of critical water quality parameters, including dissolved oxygen, pH, nitrate concentration, and biofloc density. Proper management of these parameters is essential to maintain microbial stability, prevent disease outbreaks, and maximize production efficiency (Munaeni et al., 2022).

Despite its numerous advantages, the adoption of biofloc technology among community-based fish farmers remains relatively limited due to inadequate technical knowledge, insufficient practical training, and limited access to extension services. Consequently, strengthening farmers' competencies through education and technical assistance is essential for promoting sustainable aquaculture and improving household livelihoods.

2.2. Asset-Based Community Development (ABCD) Approach

Asset-Based Community Development (ABCD) is a participatory development approach that emphasizes the identification and utilization of existing community assets

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rather than focusing solely on community problems or deficiencies. These assets include human resources, local knowledge, social networks, natural resources, infrastructure, and institutional capacity. By recognizing and mobilizing these resources, communities are encouraged to become active participants in designing, implementing, and sustaining development initiatives.

Within community-based aquaculture, the ABCD approach provides an effective framework for increasing farmers' capacity to adopt technological innovations. Through participatory training, mentoring, and collaborative learning, farmers are encouraged to utilize their existing knowledge while acquiring new technical competencies related to fish culture management. This approach strengthens community ownership of innovation and increases the likelihood of long-term adoption.

In the context of biofloc-based tilapia farming, the ABCD approach facilitates the transfer of knowledge regarding water quality management, feed preparation, disease prevention, financial management, and routine monitoring of biofloc systems. The integration of local experience with scientific knowledge enables farmers to optimize available resources while minimizing production costs. Furthermore, collaborative learning enhances farmers' confidence in implementing environmentally friendly aquaculture practices and improves their capacity to solve operational problems independently.

The application of the ABCD approach is expected to generate both economic and social benefits. Economically, improved technical competencies contribute to higher productivity, lower production costs, and increased household income. Socially, community participation strengthens cooperation among farmer groups, enhances knowledge sharing, and promotes sustainable management of local aquaculture resources. Therefore, combining biofloc technology with participatory community empowerment provides a comprehensive strategy for supporting sustainable freshwater aquaculture development.

3.1. Research Design

This study employed a community-based participatory research (CBPR) design using the Asset-Based Community Development (ABCD) approach to strengthen the capacity of tilapia farmers in implementing biofloc technology. The study combined descriptive qualitative and quantitative approaches to evaluate the effectiveness of training and mentoring activities in improving participants' knowledge, technical skills, and economic potential. The research was conducted from January to April 2026 in Paccerakkang Sub-district, Makassar City, South Sulawesi, Indonesia, where community-based tilapia farming has become an important alternative source of household income.

3.2. Participants and Research Setting

The participants consisted of members of community-based tilapia farmer groups and local residents interested in freshwater aquaculture. Participants were selected using purposive sampling based on three criteria: (1) actively engaged or interested in tilapia farming, (2) willingness to participate throughout the training and mentoring program, and (3) availability to complete evaluation activities. Local fisheries extension officers and aquaculture experts also participated as resource persons during the implementation of the program.

3.3. Community Empowerment Intervention

The intervention was implemented through four sequential stages based on the ABCD framework.

Stage 1: Asset Identification and Socialization. Existing community assets, including human resources, available land, local knowledge, and community organizations, were identified through field observations and focus group discussions. Initial socialization activities

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introduced the objectives and expected outcomes of the program.

Stage 2: Technical Training. Participants received theoretical and practical training on biofloc-based tilapia farming, including pond preparation, biofloc formation, water quality management, continuous aeration systems, feed management, seed selection, disease prevention, harvesting techniques, and simple financial record-keeping.

Stage 3: Mentoring and Field Assistance. Continuous mentoring was conducted during the cultivation process. Researchers and fisheries extension officers provided direct technical assistance, monitored implementation, identified operational constraints, and recommended corrective actions to ensure proper adoption of biofloc technology.

Stage 4: Evaluation and Follow-up Planning. The final stage evaluated participants' knowledge acquisition, technical competencies, and perceptions regarding the usefulness of biofloc technology. Recommendations for future community empowerment programs were formulated collaboratively with participants.

3.4. Data Collection

Data were collected using multiple techniques to enhance the credibility of the findings.

1. Observation was conducted throughout the implementation process to assess participants' technical performance and the application of biofloc management practices.
2. Semi-structured interviews were undertaken with farmer group leaders, participants, and fisheries extension officers to identify implementation challenges, perceived benefits, and opportunities for further development.
3. Questionnaires were administered before and after the training program to evaluate changes in participants' knowledge and understanding of biofloc technology.
4. Documentation included photographs, field notes, attendance records, training materials, and community reports supporting the implementation process.

The use of multiple data sources enabled methodological triangulation, thereby improving the validity and reliability of the research findings.

3.5. Data Analysis

Qualitative data obtained from interviews, observations, and documentation were analyzed using thematic analysis, which involved data reduction, coding, categorization, interpretation, and conclusion drawing. Quantitative data collected from questionnaires were analyzed using descriptive statistics, including frequencies, percentages, means, and standard deviations, to describe participants' characteristics and changes in knowledge following the intervention.

To evaluate improvements in participants' knowledge, pre-training and post-training scores were compared descriptively. Where appropriate, a paired-sample statistical analysis may be applied to determine whether observed improvements were statistically significant.

3.6. Indicators of Program Success

The effectiveness of the community empowerment program was evaluated using several indicators:

1. increased knowledge regarding biofloc technology;
2. improved practical skills in biofloc-based tilapia cultivation;
3. enhanced understanding of water quality management, feeding strategies, and disease prevention;
4. improved ability to prepare simple financial records;
5. increased community readiness to adopt biofloc technology sustainably; and
6. participants' perceptions of the potential contribution of biofloc farming to

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household income and community welfare.

3.7. Ethical Considerations

Participation in this study was voluntary. Prior to data collection, all participants were informed about the objectives of the research and agreed to participate through informed consent. Participant confidentiality and anonymity were maintained throughout the study, and all collected data were used exclusively for academic research purposes.

The implementation of biofloc-based tilapia farming demonstrated significant potential for optimizing limited land resources while improving the productivity and competitiveness of community-based aquaculture. The training and extension program indicated that participants gained a better understanding of biofloc cultivation techniques, particularly regarding seed selection, stocking procedures, water quality management, and the role of beneficial microorganisms in maintaining pond ecosystems. Participants also developed practical skills in managing tarpaulin ponds equipped with continuous aeration systems, which are essential for sustaining microbial activity and ensuring optimal fish growth.

The mentoring activities further strengthened participants' technical competencies through direct field assistance during the cultivation process. Farmers learned that successful biofloc formation depends on four essential components: an adequate carbon source, organic matter derived from uneaten feed and fish waste, decomposing microorganisms, and sufficient dissolved oxygen. Continuous aeration facilitates the suspension of organic particles, allowing aerobic heterotrophic bacteria to decompose organic matter and assimilate inorganic nitrogen compounds such as ammonia into microbial biomass. These microbial flocs subsequently serve as an additional natural feed source for tilapia, thereby improving feed efficiency and water quality.

The findings confirm that biofloc technology offers an effective solution for intensive aquaculture by reducing inorganic nitrogen accumulation while simultaneously providing supplementary protein through microbial biomass. This dual function contributes to improved fish growth, reduced feed costs, and enhanced production efficiency, supporting previous findings reported by Sukardi, Soedibya, and Pramono (2018). Furthermore, the technology enables higher stocking densities without compromising water quality, making it particularly suitable for small-scale farmers with limited land and water resources.

Training outcomes also demonstrated that participants recognized the economic potential of tilapia farming as a high-demand aquaculture commodity. The adoption of improved cultivation practices—including proper seed selection, water quality monitoring, feeding management, and disease prevention—is expected to increase productivity and improve household income. Figure 1 presents the discussion session involving fisheries experts, agricultural extension officers, and members of the tilapia farmer groups during the technical training on biofloc technology.

From a business perspective, maintaining water quality is a critical factor influencing the competitiveness of tilapia farming. Proper management of biofloc ponds not only improves fish health and growth performance but also enhances product quality, enabling farmers to compete in increasingly competitive markets. As market competition continues to intensify, farmers are required to adopt innovative production techniques and improve operational efficiency to satisfy changing consumer demands. Entrepreneurial characteristics such as discipline, persistence, and consistency also play an important role in strengthening the competitiveness of small-scale aquaculture enterprises (Ibrahim, Ramli, & Azis, 2021).

The study further revealed that tilapia farming contributes substantially to local

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economic development by generating employment opportunities and increasing household income. Nevertheless, several operational challenges remain, including limited knowledge of disease prevention, inadequate seed handling before stocking, and insufficient financial management practices. Most participants had not previously maintained systematic financial records, making it difficult to evaluate production costs and business profitability. Consequently, training on simple bookkeeping, including cash inflow and cash outflow recording, was integrated into the community empowerment program to strengthen participants' managerial capabilities.

The sustainability of biofloc-based aquaculture depends not only on technological adoption but also on continuous innovation in cultivation management. Improvements in seed quality, water quality control, feeding strategies, and harvesting techniques are essential for reducing production costs while increasing profitability. These findings are consistent with Hendriana et al. (2022), who emphasized that sustainable tilapia production requires continuous technological innovation and effective cultivation management.

Feed management remains one of the most important determinants of production performance. Efficient feeding practices require appropriate feed quantity, feeding frequency, and feeding methods that correspond to the nutritional requirements and feeding behavior of tilapia. Adequate nutrition supports optimal fish growth while minimizing feed waste and maintaining water quality (Eka, 2021). In the biofloc system, heterotrophic bacteria further improve feed efficiency by converting organic waste into microbial protein, which serves as a supplementary food source for cultured fish.

Another important finding concerns the improvement of participants' knowledge regarding seed production and hatchery management. Training activities enhanced farmers' understanding of administrative management, production planning, and the use of appropriate equipment to improve seed quality. In addition, participants recognized the importance of biological approaches in maintaining water quality through the activity of heterotrophic and autotrophic bacteria. Biofloc technology utilizes the metabolic capacity of these microorganisms to convert organic waste into stable microbial aggregates (bioflocs), thereby improving water quality and creating a more sustainable aquaculture system (Andik Sudirman et al., 2023).

Overall, the results demonstrate that integrating biofloc technology with community-based training and mentoring effectively improves farmers' technical knowledge, managerial capacity, and readiness to adopt sustainable aquaculture practices. These improvements are expected to contribute to higher productivity, greater production efficiency, and increased household income among tilapia farming communities in Paccerakkang, Makassar.

4.1. Research Results

The implementation of the community empowerment program demonstrated that participants showed substantial improvements in their understanding and practical application of biofloc-based tilapia farming. During the training and mentoring activities, participants acquired knowledge regarding pond preparation, biofloc formation, water quality management, seed selection, feeding strategies, disease prevention, harvesting techniques, and simple financial management. Field observations indicated that participants were able to apply these practices more confidently after receiving direct technical assistance from the research team and fisheries extension officers.

One of the major outcomes of the program was the increased understanding of biofloc technology as an environmentally sustainable aquaculture system. Participants recognized that biofloc technology functions by converting organic waste, uneaten feed, and fish excreta into microbial biomass through the activity of heterotrophic bacteria. The resulting

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microbial flocs serve as an additional natural protein source for tilapia while simultaneously improving water quality by reducing ammonia accumulation. This finding is consistent with Saridu et al. (2023), who reported that biofloc technology effectively converts inorganic nitrogen compounds into microbial protein that can be utilized as supplementary fish feed.

The mentoring process also identified several technical constraints previously experienced by farmers. These included inadequate seed selection, poor handling during stocking and harvesting, limited knowledge of disease prevention, and weak financial management practices. Conventional harvesting methods frequently resulted in high mortality rates during harvesting and transportation, while pond cleaning required considerable time and increased production costs. Following the training program, participants demonstrated improved awareness of appropriate harvesting techniques and pond management practices that could reduce fish mortality and improve production efficiency.

In addition to technical competencies, the program strengthened farmers' managerial capabilities. Participants received guidance on maintaining simple financial records, including cash inflows and cash outflows, enabling them to monitor operational costs and evaluate business performance more effectively. The integration of technical and managerial training is expected to enhance the sustainability of community-based tilapia farming enterprises.

Figure 1 illustrates the implementation of the training and mentoring activities conducted directly at the biofloc ponds, where participants practiced biofloc management under the supervision of fisheries experts and extension officers.

Figure 1. Training and field mentoring activities on biofloc-based tilapia farming conducted in Paccerakkang Sub-district, Makassar City.

4.2. Research Discussion

The findings demonstrate that biofloc technology represents an effective solution to several challenges commonly encountered in intensive tilapia farming, particularly those related to water quality deterioration, feed efficiency, and limited land availability. By utilizing heterotrophic microorganisms to recycle organic waste into microbial biomass, the biofloc system creates a more stable aquatic environment while providing an additional natural food source for cultured fish. Consequently, farmers are able to maintain higher stocking densities without significantly compromising water quality.

The successful implementation of biofloc technology, however, depends on appropriate pond management. Continuous monitoring of dissolved oxygen, pH, nitrate concentration, and biofloc density is essential to maintain microbial activity and fish health. Proper water preparation begins with pond filling, followed by the addition of minerals such as salt and dolomite to stabilize water quality. Probiotic solutions mixed with molasses are subsequently introduced to stimulate the growth of beneficial microorganisms. Regular probiotic application throughout the cultivation period promotes biofloc development and supports the biological decomposition of organic waste, thereby improving feed utilization and reducing environmental pollution (Cahrial & Noormansya, 2020).

Continuous aeration represents another critical component of the biofloc system. Adequate oxygen availability supports the metabolism of heterotrophic bacteria and prevents anaerobic conditions that may lead to ammonia accumulation and declining water quality. Therefore, blowers or aerators should operate continuously throughout the production cycle to maintain stable environmental conditions for both microorganisms and cultured fish.

Beyond its technical advantages, the study highlights the socioeconomic benefits of adopting biofloc technology. Participants

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perceived that improved cultivation practices have the potential to increase production efficiency, reduce operational costs, and improve household income. The technology also enables fish farming to be conducted on relatively small areas of land, making it particularly suitable for urban and peri-urban communities with limited cultivation space. These findings support previous studies indicating that biofloc technology contributes to sustainable aquaculture through increased productivity, efficient resource utilization, and environmental conservation (Hendriana et al., 2022).

The mentoring program further demonstrated that technical innovation alone is insufficient to ensure successful technology adoption. Farmers also require continuous capacity building in business management, financial administration, and entrepreneurial skills. Strengthening these competencies enables farmers to make better production decisions, manage business finances more effectively, and improve market competitiveness. Therefore, integrating technological innovation with community empowerment provides a comprehensive strategy for enhancing both the economic sustainability and environmental resilience of small-scale tilapia farming.

Overall, the findings indicate that the combination of biofloc technology, participatory training, and continuous mentoring contributes positively to farmers' technical knowledge, managerial capacity, and readiness to implement sustainable aquaculture practices. These improvements are expected to increase productivity, strengthen household livelihoods, and support the long-term development of community-based freshwater aquaculture in Paccerakkang, Makassar.

5.1. Conclusion

This study demonstrates that the implementation of biofloc-based tilapia farming through a community empowerment approach effectively enhances farmers' technical knowledge, practical skills, and managerial capacity. The training and mentoring program improved participants' understanding of pond preparation, water quality management, biofloc formation, feeding strategies, disease prevention, harvesting techniques, and simple financial management. The adoption of biofloc technology enables more efficient feed utilization, improves water quality, reduces environmental impacts, and supports higher aquaculture productivity. These improvements are expected to contribute positively to household income and the long-term sustainability of community-based tilapia farming in Paccerakkang Sub-district, Makassar City.

5.2. Practical Implications

The findings provide practical implications for community empowerment programs, fisheries extension services, and local governments. Biofloc technology offers an appropriate solution for small-scale farmers with limited land and water resources by improving production efficiency while maintaining environmental sustainability. Furthermore, integrating technical training with business management and financial literacy strengthens farmers' entrepreneurial capacity and supports the development of more competitive aquaculture enterprises. The study also highlights the importance of continuous mentoring to ensure the successful adoption of innovative aquaculture technologies.

5.3. Theoretical Implications

This study contributes to the literature on sustainable aquaculture and community empowerment by demonstrating the complementary relationship between biofloc technology and the Asset-Based Community Development (ABCD) approach. The findings suggest that technological innovation alone is insufficient to improve farmers' livelihoods unless accompanied by participatory capacity-building initiatives that strengthen technical competencies, managerial skills, and

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community engagement. Consequently, the study expands existing knowledge regarding the role of community-based interventions in facilitating sustainable technology adoption within small-scale aquaculture.

5.4. Research Limitations

Several limitations should be acknowledged. First, the study was conducted within a single community in Paccerakkang Sub-district, limiting the generalizability of the findings to other geographical contexts. Second, the evaluation primarily focused on participants' knowledge and skills following the training program, while long-term impacts on productivity and household income were not comprehensively measured. Third, the study employed predominantly descriptive analyses without incorporating advanced statistical techniques to quantify the magnitude of program effectiveness. Future studies should address these limitations by involving larger samples, multiple research locations, and longitudinal observations.

5.5. Recommendations for Future Research

Future research should examine the long-term economic and environmental impacts of biofloc technology by measuring indicators such as production yield, feed conversion ratio (FCR), survival rate, profitability, and household income. Comparative studies between conventional and biofloc farming systems would provide stronger empirical evidence regarding production efficiency and sustainability. In addition, future investigations are encouraged to employ quantitative or mixed-method approaches using advanced statistical analyses, such as Structural Equation Modeling (SEM), Partial Least Squares (PLS-SEM), or longitudinal impact evaluation, to better understand the relationships among farmer capacity, technology adoption, productivity, and socioeconomic welfare.

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