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Editorial

Sustainable Innovations in Shrimp Aquaculture: Current Advances and Future Horizons

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1. Introduction

With global seafood demand projected to increase by 38% by 2050 [1], the shrimp aquaculture industry faces pressing challenges in balancing production growth with environmental sustainability [2]. This Special Issue, "Advances in Shrimp Aquaculture: Management and Sustainability", presents cutting-edge research addressing three key industry challenges: (1) optimizing production systems for environmental sustainability, (2) developing effective disease prevention strategies, and (3) implementing circular economy approaches in aquaculture.

Emerging evidence demonstrates that sustainable aquaculture practices, particularly improved feed efficiency and bioremediation, can substantially enhance seafood production while reducing environmental impacts [3,4]. Nevertheless, persistent challenges including disease outbreaks, water pollution, and reliance on finite marine resources continue to hinder industry progress [5]. The five studies in this collection exemplify innovative solutions ranging from biofloc technology applications to integrated multi-trophic aquaculture (IMTA) systems. By synthesizing these findings, we highlight their collective contribution to advancing sustainable shrimp aquaculture practices while identifying critical areas requiring further investigation.

2. Key Contributions of the Special Issue

This collection presents significant advances in addressing fundamental challenges in shrimp aquaculture. Xu et al. [6] demonstrate conclusively that biofloc systems maintain optimal water quality at remarkably high stocking densities (600 shrimp/m^3), providing an effective solution to intensive aquaculture challenges. Their findings reveal that biofloc technology not only reduces water exchange requirements but also enhances nutrient recycling, contributing to global efforts to minimize aquaculture's environmental impact.

Complementing this work, Ren et al. [7] investigate microbial community dynamics in different aquaculture systems, showing that biofloc systems foster more stable microbial ecosystems compared to traditional ponds, thereby reducing pathogenic outbreaks and improving survival rates. These findings align with recent progress in microbiome management for disease prevention.

Two pioneering studies explore bioremediation approaches for effluent management and the re-utilization of resources. Li et al. [8] establish that Gracilaria–oyster IMTA systems can greatly reduce nitrogen levels by an impressive 65%, while Sun et al. [9] demonstrate that fish–alga coupling effectively recycles nitrogen and phosphorus from shrimp culture

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effluents. These findings support the growing adoption of nature-based solutions in aquaculture waste management, offering scalable strategies for reducing eutrophication risks in coastal ecosystems.

Additionally, Ferreira Colares et al. [10] contribute to the growing research on functional feed additives, demonstrating that polyphenol supplementation enhances both growth performance and antioxidant capacity in *Penaeus vannamei*. Their work provides a promising alternative to synthetic growth promoters, which have raised concerns over residues and antibiotic resistance. Collectively, these studies advance our understanding of sustainable shrimp aquaculture while providing practical solutions for industry stakeholders.

3. Emerging Challenges and Research Priorities

3.1. Environmental Pollution and Ecological Restoration

The rapid expansion of shrimp aquaculture has intensified environmental pressures, necessitating urgent mitigation strategies. Artificial compound feeds with low digestibility contribute to excessive nitrogen and phosphorus discharge, exacerbating coastal eutrophication [11]. Additionally, groundwater over-extraction for shrimp aquaculture has led to soil salinization, rendering abandoned ponds unsuitable for agriculture and damaging adjacent ecosystems [12]. Future research should focus on the following: (1) developing nutrient-efficient feeds: creating low-pollution formulations with improved protein retention; (2) advancing land rehabilitation: exploring the phytoremediation and microbial-based restoration of abandoned ponds.

3.2. Feed Utilization and Waste Reduction

Inefficient feeding practices incur substantial economic losses and environmental impacts, with 25–30% of high-protein feeds remaining unconsumed due to manual feeding inaccuracies in shrimp aquaculture [13]. Over-reliance on fishmeal further exacerbates sustainability concerns, despite promising alternatives such as fermented soybean meal and insect-based proteins [14]. The key research directions include the following: (1) automated feeding systems: implementing AI-driven technologies for precision feeding; (2) functional additives: expanding the adoption of probiotics, enzymes, and immunostimulants to enhance feed efficiency.

3.3. Aquaculture Disease and Biosecurity Threats

Shrimp aquaculture suffers frequent disease outbreaks, particularly from AHPND (acute hepatopancreatic necrosis disease), vibriosis, and EHP (*Enterocytozoon hepatopenaei*) in recent years [15]. Moreover, intensive aquaculture practices have exacerbated pathogen resistance and environmental contamination [16]. Strengthening biosecurity measures has become critical for sustainable intensive aquaculture systems. The key research priorities include (1) breeding disease-resistant strains through marker-assisted genomic selection; (2) developing probiotics and immunostimulants targeting specific pathogens; and (3) implementing closed production systems including biofloc technology (BFT) and recirculating aquaculture systems (RAS) to reduce water exchange.

3.4. Technological and Production System Limitations

Traditional earthen ponds dominate shrimp aquaculture but suffer from high water exchange rates, low production efficiency, and weak climate change resilience [17]. While increasing stocking densities can boost yields, inadequate system controls often lead to crashes due to poor water quality management and disease outbreaks [18]. Promising innovations to address these limitations include (1) upgrading facility systems through BFT and RAS to reduce water use while improving waste management [19], and (2) applying smart management technologies such as IoT-based monitoring systems for real-time water quality and health assessment, automated feeding devices, and AI-driven disease prediction models to enhance production efficiency and sustainability [20]. These advancements are essential for transitioning from traditional, resource-intensive practices to precision-controlled, sustainable shrimp aquaculture.

4. Conclusions

The research presented in this Special Issue represents significant advancements in sustainable shrimp aquaculture, offering innovative solutions across three critical dimensions: (1) optimized production systems that enhance efficiency while reducing environmental footprints, (2) improved environmental management strategies that mitigate ecological impacts, and (3) novel feed formulations that promote both animal health and resource sustainability. These collective contributions provide a robust scientific foundation for transforming aquaculture practices.

Looking forward, we identify three priority research directions essential for the sector's sustainable development: (1) technology integration: combining emerging digital technologies (AI, IoT sensor networks, automation) with traditional aquaculture knowledge to develop smart farming systems; (2) climate resilience: developing adaptive strategies to address warming waters, ocean acidification, and extreme weather events; (3) circular economy: creating value-added products from aquaculture byproducts to maximize resource utilization and minimize waste.

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