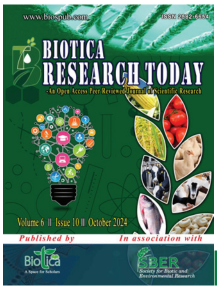

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Flocponics: Sustainable Intensification of Aquaculture by Integrating Aquaponics and Biofloc Technology

Potluri Sai Kishore, Udipta Roy, Kinnera Tejaswini, Suraj Patel and MD Aklakur*

ICAR-Central Institute of Fisheries Education, RRTC Centre, Motipur, Bihar (843 111), India

Corresponding Author

MD Aklakur

: aklakur@cife.edu.in

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Abstract

Flocponics is an innovative aquaculture model combining aquaponics and biofloc technology to promote aquaculture sustainability and the development of a circular economy. This novel technique would help solve the technical, economical and environmental challenges of traditional aquaculture by promising improved resource utilization, waste management and less adverse environmental impacts. By merging the fish culture with hydroponics and microbial flocs, this technique makes it easier to create a closed-loop, self-efficient system. Its use promotes the recycling of nutrients as the waste outputs are diminished due to synergistic interactions between fish and plants. Key components for the flocponics system include fish culture tanks, hydroponic beds and water filtration units. Even though high initial costs and system complexity might hinder the system establishment, careful monitoring and management can increase the system's profitability. Potential resource efficiency and enhanced productivity promote sustainability in flocponics as an advanced aquaculture practice.

Keywords: Flocponics, Microbial flocs, Sustainability, Waste recirculation

Introduction

Aquaculture has grown as a leading food production sector targeting nutritional security worldwide while reducing the reliance on wild fish catches. However, issues with production capacity, waste management and environmental sustainability frequently hinder traditional aquaculture methods (Boyd *et al*., 2020). Thus, to ensure technical feasibility and economic viability for the future, novel technologies aimed at sustainability must be developed (Pinho *et al*., 2023). For instance, the novel aquaculture technologies of interest are closed aquaculture systems, such as the RAS-recirculating aquaculture system and BFT-biofloc technology. These systems have high production capacity at lower water consumption, with several ongoing research studies alongside commercial applications. RAS is a screening-based aquaculture system in which water is recirculated and reused continuously using mechanical and biofilters to remove compact, suspended and toxic metabolic wastes and purify the water (Boyd *et al*., 2020). Aquaponics integrates this RAS technology with hydroponics, symbiotically targeting optimized plant production and sustainable fish culture. The effluent of RAS will be used as a source of nutrients for plant growth after a series of microbial transformations and bio-filtered water will be recirculated to RAS for fish culture. BFT is a closed-loop system targeting the developement of heterotrophic microbes along with nitrogenizing bacteria in the aquaculture tanks (Avnimelech, 2009). The key advantages that RAS and BFT have over traditional systems are that they produce aquaculture animals in a controlled condition, using recirculated water and within expectable harvesting sessions.

Despite the advances, these aquaculture systems too have a few drawbacks. The issues concerning biofloc include water quality maintenance, suspended solids and the build-up of toxic nitrogenous compounds (Boyd *et al*., 2020). Drawbacks in traditional RAS-integrated aquaponics include heavy hydroponic infrastructure, maintenance, feed input costs, disease vulnerability, inefficient balancing of biofiltration, nutrient dynamics and effluent pollution and restricted production efficiency. The effluent discharge into natural water bodies is a probable cause of environmental pollution

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leading to eutrophication. The traditional configurations of RAS and BFT acquaint monoculture systems that may not assimilate the unused nutrients to sustain other species. Considering the above drawbacks, a novel concept called flocponics has been proposed, targeting the concepts of waste recycling through trophic interactions.

Concept of the Flocponics

Flocponics, a hybrid of "flocculation" and "hydroponics", is an integrated system of aquaculture that associates fish farming and hydroponic-based plant cultivation using suspended microbial flocs as a nutrient source, forming a single symbiotic ecosystem. The term "Flocponics" was first contrived by Pinho *et al*. (2022), reporting it as an alternate type of aquaponics with previous designations as "BFT+aquaponics" or "BFT+hydroponics". Flocponics is a novel approach for an intensified aquaculture system by replacing RAS components in the aquaponics system with a biofloc (BFT) subsystem, where plants can be used as filters to eliminate dissolved nutrients. Flocponics systems possess high nutrient reuse efficiency and reduction of waste capacity compared to individual RAS and BFT (Pinho *et al*., 2023). In the flocponics system, fish are cultivated in biofloc tanks and their nutrient-rich wastewater is recirculated to nourish the plants grown in a soilless medium, thus imposing the nutrient film technology of RAS. Here, the nitrogenous compounds from the waste material are broken down into bioavailable nutrients by the microbial consortia, which the plants utilize. To date, scientists' views on flocponics are mostly towards plant production along the culture of aquatic species on the same scale. However, this technology can potentially broaden into aquaculture, targeting the commercial culture of high-valued aquatic species like Pacific white shrimp, Nile tilapia, catfish, *etc*.

Components of the Flocponics System

The flocponics system combines biofloc, RAS and aquaponics, so the design should include all the components covering all water filtration and circulation aspects (Pinho *et al*., 2022; Hwang *et al*., 2023). The design includes subsystems like fish-culture tanks, a hydroponic plant bed or plant grow trays for plant cultivation, water circulation systems, solid waste removal units (clarifier or settling tank), biological filtration units (biofilters), monitoring and control systems (Figure 1). Fish culture tanks should be equipped with suspended bioflocs. The solids removal unit separates suspended solids from the water and returns them to the culture tanks, while the nutrient-rich effluent is sent into the hydroponic plant beds. These components functions in an organized closed-loop nutrient cycling that produces microbial biomass and dissolved nutrients from the transformation of fish waste and uneaten feed, which are then absorbed by hydroponically cultivated plants. This technique assists in minimizing the nutrient loss and promoting resource efficiency in aquaculture production (Pinho *et al*., 2022).

Flocponics systems can be designed in numerous configurations, including recirculating aquaculture systems (RAS), integrated aquaponics systems and raft-type aquaponic systems. The design and operation of a flocponics system depends on several factors, such as species selection, stocking density, availability of space, production goals and environmental conditions. The selection of fish species depends on factors like water temperature and pH tolerance, feeding behaviour, growth rate and market demand (Pinho *et al*., 2022). Commonly used fish species include tilapia, trout, catfish and carp (Hwang *et al*., 2023). Generally, the selected species should be able to feed on the flocs, thus reducing feed input costs and should be commercially important to obtain maximum profit. Fishes should be compatible with the plants cultured in the hydroponics subsystem, supplementing nutritional requirements, microbial communities and water quality parameters, though further research in nutrient dynamics is required.

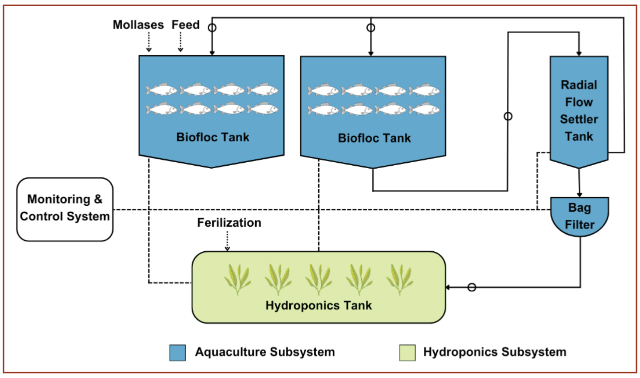

Figure 1: Model of flocponics system (Source: Pinho *et al*., 2022)

1. Biofloc Subsystem (Microbial Flocs)

Microbial flocs, or biofloc or microbial aggregates, are complex communities of bacteria, algae, protozoa and other microorganisms bound together in a gelatinous matrix (Avnimelech, 2009). These suspended matured flocs play a critical role in the flocponics system by facilitating the conversion of organic matter into bioavailable nutrients for plant uptake. In flocponics, the fish excrete waste containing ammonia, which is converted by nitrifying bacteria in the bioflocs into beneficial nitrates, a form of nitrogen that is a vital nutrient for plants.

2. Hydroponic Subsystem Components

Plants can be grown hydroponically in the flocponics system, including leafy greens, herbs, fruits and vegetables. While selecting the candidate plants for the hydroponic subsystem, several factors should be considered, including their growth characteristics, nutrient requirements, water circulation efficiency, market demand and compatibility with the fish of concern. Plants can grow in floating raft beds/ DWC-deep water culture, NFT-nutrient film technique channels, or media-filled beds within the flocponics system. Until now, most Flocponics research has assessed the culture of leafy vegetables, such as lettuce or Salicornia, which are frequently cultured in traditional aquaponics, primarily due to their minimal nutrient demand and faster production period.

3. Water Circulation and Filtration Systems

The main aim of filtration systems is to recover the decanted suspensions for the biofloc subsystem by recirculating the water through the filters. After being propelled into a settling tank, the water from the biofloc was allowed to settle. The supernatant was then sent into the hydroponics subsystem after being filtered using a five µm bag filter. This filtration results in a 71% decrease in suspended solids in the water (Pinho *et al*., 2023). The biological filtration unit (biofilters/mineralization tanks) facilitates the conversion of fish wastes into plant-available nutrients through microbial action. Installing efficient water circulation systems such as pumps, pipes, valves and motors helps maintain ideal water flow, filtration, aeration and nutrient circulation inside the system. Further studies are required to standardize these settings. Maintaining the health and productivity of fish and plants in flocponics systems depends on regular monitoring of water pH, dissolved oxygen, ammonia, nitrites, nitrates at optimal levels. Sensor-based automated control systems might assist in controlling aeration, water flow and nutrient recycling to maximize the system's performance and reduce risks.

Advantages of Flocponics in Aquaculture

As the flocponics system discharges 10% less solid waste than the traditional biofloc system, it has a greater resource reuse efficiency (Pinho *et al*., 2023). Flocponics minimizes its external feed and water input dependency by utilizing the nutrient recycling to its maximum capability. Pinho *et al*. (2022) reported that tilapia juveniles cultured in the flocponics system exhibited an increased growth, weight gain and reduced feed conversion ratio in contrast to the biofloc-based monoculture and traditional aquaponics. The following benefits may justify flocponics as a sustainable technique in technical, environmental and economic aspects:

- Flocponics fosters minimal water consumption with its water recirculation throughout the plant bed and utilizes the effective water purification capabilities of biofloc.
- This system promotes a circular economy through minimal inputs in the assorted production of several fish and plant varieties.
- Intensive fish culture leads to higher production rates within the limited space available.
- Reduced plant fertilization is observed due to the efficiency of aquaculture water in promoting plant growth, nutritional budgeting and optimized yields.
- Continuous nutrient recycling of toxic nitrogenous waste into bioavailable nutrients through biogeochemical cycles stimulates plant and animal growth.
- As the effluents and solid wastes may be recycled into inputs for the aquaponics system, flocponics can be termed an exemplary zero effluent discharge model.
- With the exception of pesticide usage, plants can thrive in optimal, disease-free conditions by the implementation of controlled environments and selection of tolerant plant species.
- Growing multiple crops each year helps reduce the cost per unit of biomass produced, allowing farmers to make money all year-round.
- Using plant beds as biofilters can lower initial capital and management costs when compared to traditional filtration systems.

Constraints of Flocponics System

Requirement of complex designing and management is essential to stabilize the flocponics system. Development of efficient filtration systems to effectively isolate the suspended solids in water is essential to the success of commercial flocponics (Hwang *et al*., 2023). Thus, the supernatant would be supplied for hydroponics and the floc material would be reverted to the BFT subsystem.

Balancing the biological interactions of nutrient requirements and environmental conditions for fish and plants in the flocponics system can be challenging. Variations in fish stocking density, feed quality and plant growth rates may affect nutrient dynamics and system stability. Maintenance of optimum biofloc composition, plant biomass, nutrient availability, rate of nutrient recycling and nutrient uptake are critical factors for the successful functioning of the BFT subsystem (Pinho *et al*., 2022).

Due to the risk of microbial flocs as potential reservoirs for pathogens and parasites that pose risks to fish and plant health, disease management is critical in the flocponics system. Implementing biosecurity measures, quarantine protocols and regular monitoring are essential for preventing and managing diseases in flocponics operations. Formulation of optimized standard operating procedures and Best Management Practices (BMPs) are essential for the system.

Conclusion

Intensified food production systems tend to pollute the environment; thus, the systems that attain high yields with nominal negative impacts must be fortified. Flocponics is considered as a novel approach towards the sustainable intensification of aquaculture. Nevertheless, the trade-off of the benefits for the cost of flocponics remains to be determined. Even though these challenges are prevalent, emerging research studies, innovations and industry collaborations on flocponics infer a hopeful future in transforming the progress of aquaculture toward this goal: to improve food security and sustainability worldwide.

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