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Biofloc system engineering (BFT), sustainable aquaculture and biosecurity in marine shrimp farming.

Biofloc technology (BFT) systems engineering, sustainable aquaculture, and biosecurity in marine shrimp farming

Biofloc systems engineering (BFT), sustainable aquaculture and biosecurity in marine shrimp farming

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Bioflocs (BFT) by the Marine Aquaculture Station of the Federal University of Rio Grande (EMA/FURG).

Abstract: This article analyzes the technological fundamentals, water quality dynamics, and process engineering applied to the cultivation of marine shrimp *(Litopenaeus vannamei)* in Biofloc Systems *(Biofloc Technology* - BFT). Based on literature from aquaculture engineering, applied microbiology, and biological oceanography, the study investigates the manipulation of the carbon:nitrogen (C:N) ratio for the development of heterotrophic and autotrophic microbial communities. The optimization of intensive aeration systems, the control of toxic nitrogenous waste, and the biosecurity protocols necessary to achieve high productivity and environmental sustainability are discussed.

Keywords: Biofloc technology. Sustainable aquaculture. Shrimp farming. Carbon-Nitrogen ratio. Water quality.

Abstract: This article analyzes the technological foundations, water quality dynamics, and process engineering applied to marine shrimp *(Litopenaeus vannamei)* farming in Biofloc Technology (BFT) systems. Grounded in aquaculture engineering, applied microbiology, and biological oceanography literature, the study investigates the manipulation of the carbon-to-nitrogen (C:N) ratio to develop heterotrophic and autotrophic microbial communities. It discusses the optimization of intensive aeration systems, the control of toxic nitrogenous wastes, and the biosecurity protocols required to achieve high yield and environmental sustainability.

Keywords: Biofloc Technology. Sustainable aquaculture. Shrimp farming. Carbon-nitrogen ratio. Water quality.

Introduction

Global aquaculture is undergoing a major technological transition driven by

due to the need to increase aquatic protein production without expanding land use or

fresh water, in addition to preventing pollution. According to Avnimelech (2015) and Hargreaves (2013), the

Traditional aquaculture farming systems based on extensive or semi-intensive farming.

They exhibit high water exchange rates, making the environments susceptible to infections by

External pathogens and the generation of eutrophic effluents. Thus, the emergence of systems

Intensive and recirculating use becomes the technical path to maximize biosecurity and...

feed conversion efficiency.

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Biofloc Technology (BFT) stands out as a productive paradigm due to its use of microbial communities capable of continuously sequestering nutrients in tanks fish. By stimulating the growth of heterotrophic bacteria through the addition of sources of Organic carbon, the BFT system transforms toxic nitrogen from organisms. high-quality microbial protein. The absence or drastic reduction of water exchange makes an environment free from devastating viral or bacterial diseases.

This article aims to discuss the fundamentals of engineering and applied bioprocesses. to the cultivation of marine shrimp in biofloc systems, based on references consolidated theoretical and empirical data in aquaculture science. Through systematic analysis of Mass balance, control of the Carbon:Nitrogen (C:N) ratio, dynamics of solids Regarding suspended measures and operational biosecurity, the aim is to demonstrate that precision in handling... Zootechnical management and biotechnological control of water are the determining variables for viability. economic and environmental aspects of modern shrimp farming.

Methodology

The method used in this study is based on a literature review and model analysis. Descriptions of aquaculture and aquatic microbiology structured by Timmons & Ebeling (2013) for the designs of intensive and recirculating aquaculture systems. The data will be collected from manuals of the United Nations Agriculture Organization and Food (FAO) and scientific literature on marine shrimp aquaculture.

The analysis includes physical-chemical and biological parameters of the culture water, such as Dissolved Oxygen (DO), Hydrogen Potential (pH), Total Alkalinity, Nitrogen Total Ammoniacal (NA), Nitrite (NO2ÿ), Nitrate (NO3ÿ), Total Suspended Solids (TSS) and the volume of bioflocs settling in Imhoff cones (SVI). These variables were correlated with theoretical frameworks developed by authors such as Boyd (1998) and Wasielesky et al. (2006), who investigate soil and water chemistry in aquaculture and the application of BFT to shrimp marine.

Furthermore, the study will address the energy efficiency of ventilation systems and their impact. from the introduction of external carbon sources (such as cane sugar, rice bran and dextrose). The role of microbial aggregation in the supplemental nutrition of shrimp will be studied. marine stingless bees (Litopenaeus vannamei) that, through the continuous ingestion of bioflocs, minimize the Feed conversion ratio (FCR) and reliance on high-quality commercial diets protein.

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Chapter 1: Microbiological Dynamics and Manipulation of the Carbon:Nitrogen Ratio (C:N)

The stability and functionality of a BFT system will depend on proper management of Microbial dynamics in the aquatic environment. According to Avnimelech (2015), the principle The fundamental aspect of the BFT system is the dominance of heterotrophic bacteria over algae and other bacteria. Nitrifying organisms. The assimilation of ammonia by heterotrophs is much faster than by nitrifying organisms. conventional nitrification process, providing the elimination of toxic nitrogen in a few hours.

Manipulating the carbon-to-nitrogen ratio is the operational trigger to induce the process. heterotrophic. As mentioned above, commercial shrimp feed has a low content of C:N (9:1 to 10:1) and the consequent production of ammonia in the water after digestion and excretion of Nitrogen. To stimulate the elimination of ammonia by heterotrophic bacteria and the production of With the new microbial mass, the C:N ratio of the water must be increased through precise calculation of introduction of soluble carbon sources.

The formation of biofloc aggregates results from the interaction between bacteria, microalgae, protozoa, rotifers, nematodes, and suspended organic matter, held together by Extracellular polymers produced by the microorganisms themselves. These clumps of Bioflocs, ranging from 0.1 to 2.0 millimeters in diameter, function as nutritional particles. floating organisms rich in crude protein, lipids, minerals, and vitamins. Marine shrimp, being A filter-feeding and detritivorous organism, it actively consumes these flakes throughout the day.

Controlling total alkalinity and pH is a critical requirement during stoichiometry. BFT. The heterotrophic assimilation process and, subsequently, the nitrification process. They consume large quantities of carbonate and bicarbonate ions from the water, causing a drop in blood pressure. of alkalinity and pH reduction. Continuous correction of the medium with the addition of Sodium bicarbonate or calcium hydroxide maintains alkalinity above 120 milligrams. of $CaCO_3$ per liter, ensuring the stability of the buffer system and the physiological integrity of the animals.

It can be concluded that mastering the carbon:nitrogen balance is the backbone of BFT cultivation. The biotechnological transformation of metabolic waste into edible bioflocs converts a toxic effluent in natural food, optimizing cultivation efficiency and reducing the environmental impact of shrimp farming.

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Chapter 2: Intensive Aeration Engineering, Flow Sizing and Management
Solids

Maintaining a biofloc system requires an aeration and circulation infrastructure.
Water designed with rigorous engineering standards. As Timmons and Ebeling (2013) point out,
The total biomass present in a BFT tank is not limited to the farmed shrimp, but
It encompasses billions of respiring microorganisms per cubic meter of water. The demand
Bacterial oxygen uptake often exceeds the body's own respiration rate.
Aquatic organisms are vulnerable, making any failure in the aeration system a lethal and immediate risk.
The design of the aeration system must fulfill two essential functions simultaneously:
to provide sufficient oxygen to maintain dissolved oxygen (DO) levels above 5.0 milligrams per liter and
generate mixing energy capable of maintaining all organic and inorganic solids in
Continuous suspension. The emergence of dead zones of deposition at the bottom of the tank leads to
anaerobiosis, generating foci of methanogenic fermentation and accumulation of hydrogen sulfide gas (H2S),
This compound is extremely toxic to shrimp.
The combined use of air blowers *coupled* to micro-perforated hoses
at the bottom and paddle aerators or *Venturi* injectors at the surface create a flow pattern.
Continuous three-dimensional. The speed of water circulation at the bottom of the tank must be
The flow rate is maintained between 15 and 20 centimeters per second to prevent the flocs from settling.

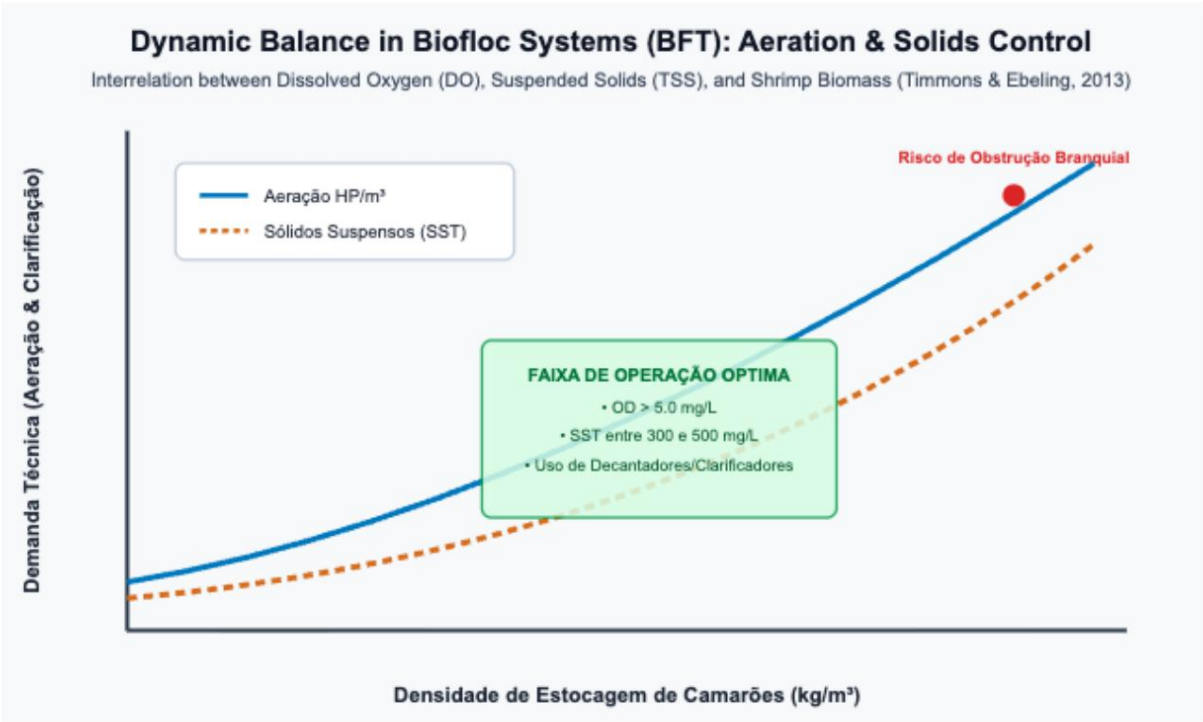

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Figure 1: Relationship between Crop Density, Aeration Demand and Accommodation of Solids in BFT Systems. Source: Adapted from Timmons and Ebeling (2013) and Avnimelech (2015).

Managing the accumulation of Total Suspended Solids (TSS) represents one of the most important aspects. sensitive to operational needs. Although bioflocs are beneficial, excessive concentrations of TSS (Total Soluble Solids) can be problematic during operation. (Exceeding 500 milligrams per liter) obstruct the gill apparatus of shrimp, inducing Asphyxia, reduced weight gain, and mortality. To maintain SST within the ideal range. For concentrations of 300 to 400 milligrams per liter, external clarifiers are used . or coupled sedimentation tanks, which remove excess sludge by gravity.

Continuous maintenance of water quality and strict control of floc volume ensure A healthy environment for the rapid development of marine shrimp. The correct Proper motor sizing and the use of frequency converters adjust power consumption. energy from the property, ensuring the economic sustainability of the crop.

Finally, the automation of oxygen monitoring through optical probes connected to Emergency generators prevent catastrophic deaths due to power outages. Redundancy Proper aeration systems and rigorous solids management are the guarantee of safety. operational for intensive aquaculture projects.

Chapter 3: Biosafety, Sanitation, and Viral Disease Mitigation Protocols and Bacteria

Biosecurity is the set of operational and structural measures aimed at preventing Introduction and dissemination of pathogens in aquaculture. According to Lightner (2011), viral diseases (such as white spot syndrome virus - WSSV) and infectious bacteriosis (such as acute hepatopancreatic necrosis - AHPND/EMS caused by strains of *Vibrio parahaemolyticus* have destroyed global supply chains, requiring a transition for closed and biosecure cultivation systems.

The architecture of the BFT system is inherently biosecure due to the absence of water exchange. with the external environment throughout the entire growing cycle. The intake of water for supply. It is carried out in advance, going through rigorous disinfection processes using chlorination. deactivation by sodium bisulfite or treatment by ultraviolet (UV) radiation and ozone before from the settlement. This prior disinfection eliminates wild disease vectors, such as crustaceans. and invasive fish.

Physically excluding external vectors requires completely covering greenhouses and tanks with screens.

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Anti-bird and anti-crab barriers on the property's edges. Mandatory disinfection.
The presence of footwear, vehicles, and handling equipment at the entrance to the cultivation area prevents...
Cross-contamination between different production modules. The use of post-larvae.
Certified as Specific Pathogen Free (SPF) ensures that
The initial batch must be free of systemic viruses and bacteria.
The natural immunomodulation provided by consuming bioflocs acts as a barrier.
biological protection in the shrimp gut. The diversity of microorganisms present in
bioflocs and the presence of bioactive compounds (such as beta-glucans, polysaccharides and acids)
Polyunsaturated fatty acids) stimulate the crustacean's innate immune system. Furthermore,
Competition for space and nutrients promoted by the high density of heterotrophic bacteria.
It inhibits the growth of pathogenic bacteria of the genus *Vibrio* through the phenomenon of exclusion.
competitive.
Therefore, biosecurity in BFT systems combines physical isolation against pathogens with
Strengthening the animals' immune and sanitary conditions. Strict application of protocols.
Sanitary measures ensure crop predictability, reduce the risk of epidemic losses, and consolidate
The sustainability of aquaculture investment.

Chapter 4: Operational Cost Modeling, Financial Feasibility, and Analysis of Risk in BFT

The financial viability and profitability of a high-tech aquaculture enterprise.
They depend on strict control of the operational cost structure and capital planning.
According to Shang (1990), the economics of intensive aquaculture is characterized by costs.
fixed and capital expenditures *(CAPEX)* significantly higher than those of traditional systems,
requiring high productivity per cubic meter to offset infrastructure depreciation,
Motors and automation systems.
The operational cost matrix *(OPEX)* in BFT systems is dominated by energy costs.
electricity for continuous aeration, commercial feed and water correction inputs (sources of
carbon, limestone, and bicarbonate). Although electricity represents a significant fixed cost,
The use of BFT provides substantial savings on feed, since the conversion
Feeding ratios can be reduced from 1.6:1 (in traditional systems) to levels of 1.0:1 to 1.2:1.
thanks to the consumption of microbial biomass by shrimp.
The modeling of the Total Production Cost per kilogram of harvested shrimp results from the sum
of the costs of post-larvae, commercial feed, carbon inputs, electricity, labor

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specialized equipment maintenance, and administrative and licensing costs.
environmental. The financial *break-even point* of cultivation requires reaching
minimum productivity of 3 to 5 kilograms of shrimp per cubic meter per cycle to exceed the
Ventilation and depreciation costs.
Risk and financial sensitivity analysis should project scenarios of price fluctuations.
Shrimp sales in the consumer market, variations in electricity rates and increases
in the price of feed ingredients (such as soybean meal and fishmeal). The capacity of
BFT (Balanced Farming Test) for conducting multiple annual cycles in covered agricultural greenhouses protects the producer against
weather inclement and price seasonality, ensuring recurring revenue over time.
all year round.

It is concluded that the economic viability of BFT is based on its high biological efficiency.
The system. The dilution of fixed costs through high productivity per area and the optimization of the factor of
Feed conversion ensures attractive financial margins for the investor, transforming
Intensive aquaculture as a highly profitable business.

Chapter 5: Operational Risks, Technological Limitations, and Critical Failure Points

Despite the high productivity rates offered by Biofloc Technology, the
BFT system operation presents technical risks and vulnerabilities that require
Continuous monitoring and high response capacity of the management teams. As per
Hargreaves (2013) warns that biofloc cultivation is a "razor's edge" system, where
Small deviations in water quality parameters can quickly escalate into...
Collapse of the tank ecosystem and total loss of the batch.
The risk of biofloc collapse *(floc crash)* is the main threat to the system's stability.
A sudden drop in the microbial community can be triggered by failures in carbon addition.
organic matter, extreme variations in solar radiation in open tanks, or improper use of
Chemotherapeutic and bactericidal agents. The collapse of the flocs causes the massive release of ammonia and
Nitrite in the water, accompanied by uncontrolled oxygen consumption due to the decomposition of
dead organic matter.
The critical dependence on electrical power makes the system extremely vulnerable to
Interruptions in the public water supply. Shutdown of aeration for periods exceeding...
Fifteen or thirty minutes in high-density storage tanks results in anoxia.
severe and mass death by asphyxiation. The implementation of automated generators of
Immediate activation *(uninterruptible power* supplies and diesel generators) is a mandatory requirement of

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infrastructure to mitigate this fatal risk.

The accumulation of nitrite (NO2ÿ) during the transition phase between the heterotrophic domain and the The establishment of nitrifying bacteria of the genera *Nitrospira* and *Nitrobacter* represents Another critical bottleneck in management. Nitrite oxidizes hemocyanin in shrimp blood. preventing the efficient transport of oxygen to the tissues. Controlling this risk requires... Daily monitoring of nitrite levels and the addition of sodium chloride (common salt) for Maintaining a chloride:nitrite ratio above 10:1 protects animals from ion toxicity.

Therefore, identifying critical points of failure and providing continuous training for the team are crucial. Operational aspects are indispensable for success in BFT. Rigorous physical-chemical testing is essential. Daily routines and the maintenance of technical contingency plans ensure the stability of the crop and They protect the assets of the enterprise.

Chapter 6: Environmental Sustainability, Licensing, and the Future of Shrimp Farming Intensive

The incorporation of the principles of environmental responsibility and circular economy into Aquaculture has become an indispensable requirement for obtaining environmental licenses and access to qualified consumer markets. According to Boyd (1998), shrimp farming Traditional practices have faced severe legal restrictions due to the conversion of mangrove areas into fish farms and the discharge of nutrient-rich effluents into estuaries and coastal waters. The BFT It emerges as the technology to eliminate these ecological impacts.

The water footprint of a BFT system is drastically lower than that of traditional aquaculture. While conventional crops consume tens of thousands of liters of water per kilogram of Shrimp produced due to daily water changes, the biofloc technology consumes only The amount needed to replace losses due to evaporation. Resource conservation. Water resources allow the installation of aquaculture farms in areas far from the coast, using water. brackish underground water sources and protecting coastal and mangrove ecosystems.

The treatment and reuse of sludge discarded from settling tanks aligns BFT with the principles. of the circular economy. The excess bioflocs removed from the system can be processed and used as a protein ingredient in feed for other aquatic species or converted into High-quality organic fertilizers for terrestrial agriculture. This integration between Aquaculture and agriculture eliminate waste disposal and generate new sources of revenue for the property.

The requirements for traceability and international sustainability certification (such as

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standards of the *Aquaculture Stewardship Council* - ASC and *Best Aquaculture Practices* - BAP) They value shrimp produced in BFT systems. This guarantees a residue-free product. antibiotics, cultivated in a biosecure manner and without impacting protected areas attracts discerning consumers willing to pay a premium price *for* protein . sustainable.

It is concluded that Biofloc Technology represents the future of sustainable shrimp farming. worldwide. The combination of water efficiency, environmental protection, biosecurity and Economic viability positions BFT as the key technology for feeding the population. Global source with excellent quality protein and minimal ecological footprint.

Final Considerations

The research developed throughout this article shows that the application of Technology Bioflocs (BFT) in marine shrimp farming is one of the most promising innovations for the The goal is to achieve sustainable, biosecure, and highly productive aquaculture. The research demonstrates that rigorous manipulation of the carbon:nitrogen (C:N) ratio allows one to transform The nitrogen excreted by animals is absorbed into protein-rich microbial biomass, promoting Nutrient recycling and water purification within the growing environment itself.

The study proves that aeration engineering and suspended solids management are the cornerstones. Operational factors that support high-density cultivation in BFT. Proper sizing of blowers, the use of external settling tanks, and continuous monitoring of dissolved oxygen. They ensure the maintenance of a healthy environment for the shrimp and the communities. beneficial microbes, preventing mortality due to anoxia or gill stress.

The inherent biosafety of BFT proves to be a decisive strategic advantage against to the global sanitary challenges of shrimp farming. Reducing water exchange to zero, combined with the biological competition exerted by heterotrophic bacteria against pathogenic microorganisms of the genus *Vibrio* protect crops against viral epidemics and bacterial control, ensuring the predictability and health of crops.

Quantitative analysis of operating costs and financial viability confirms that the reduction The low Feed Conversion Ratio (FCR) and high productivity per cubic meter compensate for this. Initial investments in infrastructure and electricity. The dilution of fixed costs by high productivity and the possibility of carrying out multiple annual cycles in covered greenhouses They ensure solid profit margins and an attractive return for the producer.

Furthermore, the adherence of BFT systems to environmental sustainability requirements and

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International market certifications consolidate the technology as a definitive model for

The future of aquaculture. Minimal water consumption, protection of coastal ecosystems and...

The possibility of reusing organic sludge as biofertilizer is integrated into the production of

Food for the circular economy.

Given the growing global demand for healthy food and increasing restrictions

to the use of natural resources, the professionalization and industrialization of intensive aquaculture

They cease to be an option and become a global imperative.

It is concluded that technical rigor, mastery of aquatic biotechnology, and commitment to...

Sustainability is the driving force behind the modernization of shrimp farming.

Continuous investment in professional training, process optimization, and innovation.

Biotechnology ensures the success of aquaculture businesses, protects the environment, and guarantees...

The supply of high-quality protein for future generations.

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