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Commentary

Biomass Production from Aquaculture Wastewaters for Sustainable Feed Applications

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DESCRIPTION

Nutrient management in aquaculture systems represents a significant challenge due to the concentration of nitrogen, phosphorus, and organic matter in wastewaters from both brackish and marine operations. Intensive aquaculture generates effluents rich in uneaten feed, feces, and metabolic byproducts, which, if released untreated, can degrade water quality, stimulate harmful algal blooms, and disrupt surrounding ecosystems. Traditional wastewater treatment methods, while effective at reducing nutrient loads, often involve high energy input, chemical usage, or low recovery of valuable compounds. Increasing attention has been directed toward integrated biological treatment approaches that not only remove nutrients but also convert them into reusable biomass suitable as feed additives for aquaculture species.

Algal-bacterial granular sludge systems are engineered microbial consortia in which microalgae and bacteria form compact, dense granules capable of efficiently processing nutrients. The granular structure provides a high surface area-to-volume ratio, facilitating simultaneous biological processes such as nitrification, denitrification, phosphorus uptake, and organic matter degradation. Microalgae within the granules capture inorganic nutrients through photosynthesis, while heterotrophic and autotrophic bacteria contribute to organic matter decomposition and nutrient cycling. The resulting biomass is nutrient-rich, containing proteins, lipids, and essential micronutrients, and can be harvested for use as an ingredient in aquaculture feeds.

The application of Algal-Bacterial Granular Sludge (ABGS) technology to brackish and marine aquaculture wastewater offers several advantages. Firstly, the systems are resilient to fluctuations in salinity, and characteristics typical of coastal aquaculture operations. Laboratory and pilot-scale studies have demonstrated that ABGS can achieve substantial reductions in total nitrogen and phosphorus concentrations while maintaining high biomass production rates. The granules' compactness facilitates sedimentation, simplifying biomass harvesting and reducing energy requirements compared with suspended algal cultures. Furthermore, the symbiotic relationship between algae and bacteria stabilizes granule formation and function, even under variable hydraulic conditions.

Harvested ABGS biomass exhibits qualities that make it suitable for incorporation into fish feeds. The protein content of microalgae-bacteria granules can range from 30 to 50 percent of dry weight, with favorable amino acid profiles for many cultured species. Lipid content, while variable, includes essential fatty acids such as omega-3 and omega-6, which are critical for fish growth, reproduction, and health. The presence of pigments, vitamins, and other bioactive compounds contributes additional nutritional value. By processing wastewater through ABGS, aquaculture operations can recycle nutrients that would otherwise be lost, simultaneously reducing environmental discharge and generating a functional feed ingredient.

Integration of ABGS biomass into fish feeds requires careful consideration of processing methods, inclusion rates, and species-specific nutritional requirements. Biomass can be dried, pelletized, or incorporated into formulated feeds as a partial replacement for conventional protein and lipid sources. Studies have demonstrated that partial replacement of fishmeal or soybean meal with algal-bacterial biomass does not compromise growth performance in several marine and brackish water species, including tilapia, seabass, and shrimp. Additionally, feed trials indicate that the presence of natural bioactive compounds in the biomass may enhance digestive efficiency, antioxidant capacity, and immune function, although these effects are context-dependent and influenced by processing and storage conditions.

The nutrient composition of ABGS biomass is influenced by wastewater characteristics, operational parameters, and granule age. Higher nitrogen and phosphorus concentrations in influent promote greater accumulation of protein and polyphosphate within the biomass. Light availability, hydraulic retention time, and dissolved oxygen levels affect photosynthetic efficiency and microbial activity, thereby influencing growth rate and nutrient

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uptake. Salinity exerts selective pressure on microbial composition, with certain halotolerant algal and bacterial strains dominating in marine systems. Optimizing these parameters is essential for producing biomass with consistent quality suitable for feed use.

Advances in reactor design and process optimization have addressed some of these challenges. Sequencing batch reactors and continuous flow systems equipped with controlled aeration, illumination, and mixing have demonstrated stable granule formation and high nutrient removal efficiencies. Coupling ABGS with pre-treatment or post-treatment stages, such as sedimentation or filtration, further enhances water quality and simplifies biomass recovery. Molecular and microbial community analyses provide insights into granule composition, enabling targeted selection of algal and bacterial strains with desirable nutrient uptake and resilience characteristics.

Environmental monitoring and life cycle assessment are also essential components of ABGS implementation. Evaluating the net reduction of nutrient loads, greenhouse gas emissions, and energy inputs provides a comprehensive understanding of the sustainability of the system. Comparative analyses with conventional wastewater treatment and feed production highlight the advantages of converting effluents into reusable biomass rather than disposing of them untreated. Incorporating these assessments into aquaculture management supports decision-making and demonstrates the environmental benefits of integrated nutrient reclamation strategies.

In conclusion, algal-bacterial granular sludge technology provides a viable approach for nutrient reclamation from brackish and marine aquaculture wastewaters. By transforming effluents into nutrient-rich biomass suitable for incorporation into fish feeds, ABGS systems address both environmental and production challenges. Long-term operation demonstrates the capacity to remove nitrogen, phosphorus, and organic matter efficiently while generating biomass with favorable protein, lipid, and micronutrient composition. Integration of this biomass into aquaculture feeds supports growth performance and may enhance immune and digestive functions in cultured species. Continued optimization of system design, operational parameters, and feed incorporation strategies is essential to fully realize the potential of ABGS technology in promoting sustainable, resource-efficient aquaculture.