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RECENT ADVANCEMENTS IN AQUACULTURE NUTRITION FOR A SUSTAINABLE FUTURE

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Aquaculture nutrition has undergone transformative innovations to address global food security, environmental sustainability, and production efficiency. Recent advancements focus on alternative protein sources, precision feeding technologies, functional feed additives, and circular economy principles. These developments reduce reliance on finite marine resources, enhance fish health, and minimize ecological footprints while meeting rising protein demands.

Protein Hydrolysates and Functional Ingredients

Protein hydrolysates are produced by enzymatic or chemical hydrolysis of proteins, resulting in smaller peptides and free amino acids that are easily digestible by aquatic organisms. In aquaculture nutrition, fish protein hydrolysates derived from fish by-products, shrimp waste, or plant proteins are increasingly used to improve feed efficiency and growth performance. These hydrolysates contain bioactive peptides that stimulate appetite, improve protein digestibility, and enhance nutrient absorption in fish and shrimp. Studies have demonstrated that diets supplemented with protein hydrolysates can improve growth rates, feed conversion ratio (FCR), and survival rates in species such as tilapia, salmon, and shrimp.

Functional ingredients, such as nucleotides, taurine, carotenoids, and bioactive peptides, also play important roles in improving physiological functions and immune responses. These compounds enhance stress resistance, antioxidant activity, and disease resistance in cultured species. For example, dietary nucleotides promote immune cell proliferation and improve resistance to bacterial infections, while taurine supplementation enhances growth and metabolic efficiency in carnivorous fish species. The inclusion of functional ingredients in aquafeeds is therefore considered a key strategy to improve productivity and sustainability in modern aquaculture systems.

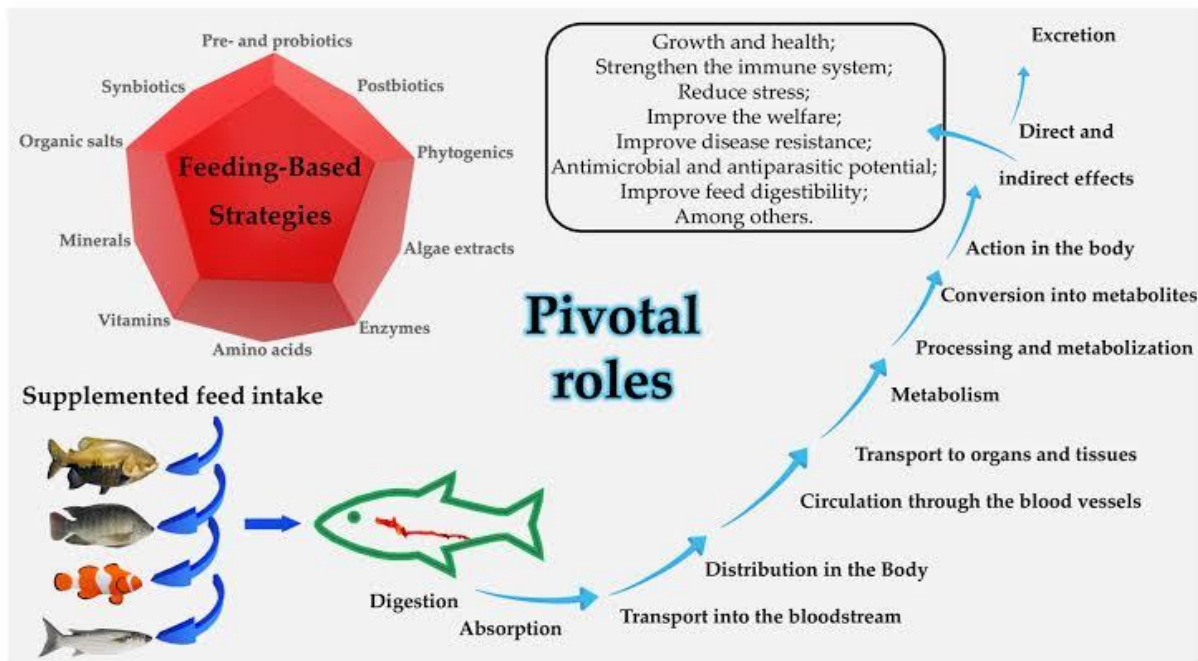


Fig. 1: Pivotal role of fish nutrition and Feeding

Smart Feeding and Precision Nutrition

Smart feeding technologies are transforming aquaculture production by improving feeding efficiency and reducing feed waste. Feed represents the largest operational cost in aquaculture, often accounting for more than 50–60% of total production expenses. Precision feeding systems use sensors, cameras, and automated feeders to monitor fish feeding behavior and deliver feed according to real-time requirements. This approach helps optimize feed utilization while minimizing environmental pollution caused by uneaten feed and nutrient discharge. Precision nutrition focuses on providing the exact nutrient requirements for aquatic organisms at different life stages. Nutrient requirements vary depending on species, size, environmental conditions, and production systems. Modern nutritional models use data analytics and computer simulations to formulate balanced diets that maximize growth while minimizing nutrient wastage. For example, dynamic feeding models can adjust feed composition and feeding frequency based on fish metabolism, water temperature, and growth rate. These advanced feeding strategies improve feed conversion efficiency, reduce production costs, and enhance the sustainability of aquaculture operations.

Alternative Protein Sources

The rapid expansion of aquaculture has significantly increased the demand for fishmeal and fish oil, which are traditionally used as primary protein and lipid sources in aquafeeds.

However, the limited availability and rising cost of these marine resources have driven the search for sustainable alternative protein sources. Plant-based proteins such as soybean meal, pea protein, corn gluten meal, and rapeseed meal are widely used as partial replacements for fishmeal in aquafeeds. These ingredients provide high protein content and are readily available, although they may contain anti-nutritional factors that can affect digestibility and nutrient utilization.

Recent research has focused on novel protein sources such as insect meals, microbial proteins, algae-based ingredients, and single-cell proteins. Insect meal derived from black soldier fly larvae has gained considerable attention due to its high protein content, balanced amino acid profile, and low environmental footprint. Similarly, microalgae and macroalgae provide essential fatty acids, vitamins, and bioactive compounds that support fish growth and health. Single-cell proteins produced from bacteria, yeast, or fungi offer promising alternatives due to their rapid production and minimal land and water requirements. The use of these alternative protein sources can significantly reduce reliance on marine resources and contribute to the sustainability of aquaculture feed production.

Insect Protein: Black Soldier Fly-derived ingredients (e.g., Palate) strengthen immune defenses in rainbow trout by activating pathogen-response genes, reducing mortality risks.

Microalgae: Autotrophic strains (e.g., *Schizochytrium* sp.) provide essential fatty acids (DHA/EPA) and amino acids, improving stress resistance and fillet quality.

By-Product Valorization: Fish processing wastes (heads, bones) are repurposed into silages or hydrolysates, enhancing gut health and reducing landfill burdens. For example, Barbados repurposes 8 tons of daily by-products into feed additives, lowering antibiotic needs.

Feed Additives and Immunonutrition

Novel additives modulate immunity and metabolism: Feed additives play an essential role in improving growth performance, health status, and disease resistance in aquaculture species. Common feed additives include probiotics, prebiotics, organic acids, enzymes, phytogenics, and immune stimulants. These additives enhance digestive efficiency, improve nutrient absorption, and strengthen the immune system of fish and shrimp. Probiotics, such as *Bacillus* and *Lactobacillus* species, improve gut microbiota balance and inhibit pathogenic microorganisms, thereby reducing disease outbreaks. Immunonutrition refers to the use of specific nutrients or bioactive compounds to modulate the immune system of aquatic

organisms. Important immunostimulants used in aquaculture include beta-glucans, nucleotides, vitamins C and E, and minerals such as selenium and zinc. These compounds enhance both innate and adaptive immune responses, increasing the ability of fish and shellfish to resist infections. For example, beta-glucans stimulate macrophage activity and enhance the production of immune-related cytokines, improving resistance against bacterial and viral pathogens.

- **β-glucan**(0.4% inclusion) optimizes intestinal microbiota in tilapia, increasing survival in brackish water by downregulating inflammatory genes.

- Andrographolide(150 mg/kg) enhances antioxidant capacity in rice field eels via Toll-like signaling pathways.

- Plant extracts(e.g., *Glycyrrhiza uralensis*) upregulate immune-related genes in barramundi, improving growth rates by 15%.

The integration of immunonutrition strategies into aquafeeds reduces dependence on antibiotics and supports sustainable disease management in aquaculture.

Probiotics, Prebiotics and Gut Health

The health and productivity of aquatic animals are closely linked to the microbial communities present in their gastrointestinal tract. Probiotics are beneficial microorganisms that improve gut microbial balance and enhance digestive enzyme activity. These microorganisms colonize the intestinal tract and compete with pathogenic bacteria for nutrients and attachment sites, thereby preventing infections. Probiotics also produce antimicrobial substances that inhibit the growth of harmful microorganisms. Prebiotics are non-digestible feed components that selectively stimulate the growth of beneficial gut bacteria. Common prebiotics used in aquaculture include fructooligosaccharides (FOS), galactooligosaccharides (GOS), and mannan-oligosaccharides (MOS). These compounds promote intestinal health, improve nutrient digestion, and enhance immune responses. When probiotics and prebiotics are combined, they form synbiotics, which provide synergistic benefits for gut health and overall performance. The use of these functional additives contributes to improved growth, disease resistance, and feed efficiency in aquaculture systems.

Sustainable Formulations and Circular Economy

Camelina meal replaces 20% of fishmeal in red seabream diets, improving digestibility and stress resilience without compromising growth.

Insect- and algae-based feeds reduce aquaculture's carbon footprint by 30–40% compared to traditional options. BRF Ingredients' portfolio exemplifies circularity, using poultry by-products to create hydrolysates, thus minimizing waste.

Conclusion

In conclusion, recent advances in aquaculture nutrition and management have significantly contributed to improving productivity, efficiency, and environmental sustainability. Innovations such as protein hydrolysates, functional ingredients, and alternative protein sources have helped reduce the dependence on traditional fishmeal and fish oil while maintaining optimal growth and health of cultured species. In addition, the development of smart feeding systems and precision nutrition strategies has improved feed utilization and minimized nutrient waste in aquaculture systems. Furthermore, the use of feed additives, probiotics, and immunonutrition has strengthened disease resistance and enhanced the overall health status of fish and shellfish. The integration of modern technologies, including digital monitoring systems and precision aquaculture tools, also plays an important role in optimizing farm management and improving production efficiency. Overall, these advancements demonstrate that sustainable aquaculture can be achieved through the combination of innovative nutrition strategies, technological developments, and environmentally responsible farming practices. Continued research and collaboration among scientists, industry stakeholders, and policymakers will be essential to ensure the long-term sustainability and resilience of the global aquaculture sector.

Reference

- Abdel-Tawwab, M., & Adeshina, I. (2022). Nanotechnology applications in aquaculture nutrition and fish health. *Aquaculture International*, 30, 1–17.
- Avnimelech, Y. (2015). *Biofloc technology: A practical guidebook* (3rd ed.). The World Aquaculture Society.
- BRF Ingredients. (2025). *Aquaculture in 2025: New technologies, sustainability and the direction of the sector*.

- Dawood, M. A. O., Koshio, S., & Esteban, M. A. (2018). Beneficial roles of feed additives as immunostimulants in aquaculture. *Reviews in Aquaculture*, *10*(4), 950–974.
- Føre, M., Frank, K., Norton, T., Svendsen, E., Alfredsen, J. A., Dempster, T., Berckmans, D. (2018). Precision fish farming: A new framework to improve production in aquaculture. *Biosystems Engineering*, *173*, 176–193.
- Glencross, B. D., Huyben, D., & Schrama, J. W. (2020). The application of nutrigenomics in aquaculture feeds. *Aquaculture Research*, *51*, 1–14.
- Handy, R. D., Owen, R., & Valsami-Jones, E. (2018). The ecotoxicology of nanoparticles and nanomaterials in aquatic environments. *Ecotoxicology*, *17*(5), 315–325.
- Houston, R. D., Bean, T. P., Macqueen, D. J., Gundappa, M. K., Jin, Y. H., Jenkins, T. L., & Martin, S. A. M. (2020). Harnessing genomics to fast-track genetic improvement in aquaculture. *Nature Reviews Genetics*, *21*, 389–409.
- Naylor, R. L., Hardy, R. W., Buschmann, A. H., Bush, S. R., Cao, L., Klinger, D. H., & Troell, M. (2021). A 20-year retrospective review of global aquaculture. *Nature*, *591*, 551–563.
- Number Analytics. (2025). *The future of aquaculture in nutrition*.
- Ringø, E., Olsen, R. E., Gifstad, T. Ø., Dalmo, R. A., Amlund, H., Hemre, G. I., & Bakke, A. M. (2016). Prebiotics in aquaculture: A review. *Aquaculture Nutrition*, *16*(2), 117–136.
- Troell, M., Joyce, A., Chopin, T., Neori, A., Buschmann, A. H., & Fang, J. G. (2009). Ecological engineering in aquaculture: Potential for integrated multi-trophic aquaculture (IMTA). *Aquaculture*, *297*, 1–9.