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Microbial Signaling, Nutritional Regulation, and Neural Control in Aquatic Animals

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DESCRIPTION

The fish gut-brain axis describes a two-way communication network connecting the gastrointestinal tract with the nervous system. This biological relationship involves intestinal microorganisms, digestive tissues, immune cells, metabolic compounds, hormones, and neural pathways. In aquaculture species, the condition of the digestive tract can influence feeding behaviour, stress responses, growth, immune activity, and general physiological performance. At the same time, signals generated by the nervous system can modify intestinal movement, secretion, appetite, and microbial conditions. Understanding this communication system provides a useful framework for examining how nutrition, water conditions, stocking density, handling, and microbial composition affect cultured fish.

The intestinal tract of fish contains diverse microbial communities that participate in digestion and nutrient transformation. Bacteria associated with the intestinal environment can process carbohydrates, proteins, lipids, and other dietary components that are not completely utilized by host digestive enzymes. Microbial metabolism produces compounds such as short-chain fatty acids, amino acid derivatives, vitamins, and other bioactive substances. These compounds may interact with intestinal cells and enter circulation, allowing information generated in the gut to influence tissues located elsewhere in the body. The composition of the intestinal microbial community can therefore affect the biochemical environment experienced by the host.

Communication between the intestine and brain occurs through several routes. Neural communication involves the enteric nervous system and the vagus-associated pathways, while endocrine communication includes hormones released in response to food intake and changes in energy status. Immune signaling also contributes to communication because intestinal immune cells can release signaling molecules in response to microbial or dietary stimuli. Metabolic compounds generated during digestion and microbial activity provide another route of information transfer. These pathways operate together rather than functioning as isolated systems.

Feeding is one of the most visible outcomes associated with the gut-brain axis. Fish regulate food intake through signals related to energy availability, stomach and intestinal activity, and nutrient absorption. Hormones such as ghrelin, cholecystokinin, leptin, and peptide YY have been studied in relation to appetite regulation in different fish species. Their functions can vary among species and developmental stages, but they provide important information about the nutritional condition of the animal. Changes in intestinal microbial activity may also modify the production or availability of metabolites that influence appetite-related signaling.

Diet composition can strongly affect this system. Fish meal replacement, plant-based ingredients, alternative proteins, dietary lipids, carbohydrates, fiber, probiotics, prebiotics, and fermented ingredients can alter the intestinal environment. A diet that changes the available nutrients can consequently change microbial abundance and metabolic activity. Such changes may affect intestinal barrier function, immune responses, digestion, and signaling to the nervous system. For aquaculture production, this means that feed formulation should be considered not only in terms of nutrient percentages but also in relation to intestinal physiology and microbial ecology.

The intestinal barrier is another important component of gut–brain communication. The epithelial lining separates the internal tissues of the fish from the contents of the intestinal tract. Tight junction proteins and mucus-associated components contribute to this protective function. When the intestinal barrier is disturbed by poor nutrition, environmental stress, pathogens, or unsuitable water conditions, microbial products may interact differently with host tissues. This can activate immune responses and alter metabolic signaling. Prolonged intestinal disturbance may also influence feeding activity, energy allocation, and behavioral responses.

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CONCLUSION

The fish gut–brain axis represents an interconnected biological communication system involving intestinal microorganisms, nutrients, metabolites, hormones, immune pathways, and neural signals. Its influence extends across feeding, digestion, metabolism, stress physiology, immunity, behavior, and development. In aquaculture, studying this system can provide additional insight into how dietary and environmental conditions affect cultured animals. Continued research combining microbiology, nutrition, neuroscience, physiology, and molecular biology may support more informed approaches to fish health and production while improving understanding of the biological connections between intestinal activity and neural regulation.