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Perspective

Shrimp Lipidome Remodeling: Metabolic Adaptation and Lipid Dynamics in Cultured Shrimp

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DESCRIPTION

Shrimp lipid metabolism is closely connected with growth, energy storage, molting, reproduction, immune activity, and adaptation to changing environmental conditions. Lipids are not simply stored energy reserves in shrimp; they also form cellular membranes, participate in signaling processes, support hormone production, and influence the physiological response to nutritional and environmental changes. The term shrimp lipidome refers to the complete collection of lipid molecules present within a biological system at a particular time. Lipidome remodeling describes changes in the abundance, composition, distribution, and transformation of these lipid molecules as shrimp respond to diet, developmental stage, water quality, temperature, salinity, disease exposure, and reproductive status.

Shrimp possess several major lipid classes, including phospholipids, triglycerides, sterols, sphingolipids, free fatty acids, lysophospholipids, and other specialized lipid molecules. Each group has a different biological function. Triglycerides are important energy reserves, while phospholipids contribute to cellular membrane structure. Sterols participate in membrane organization and steroid-related processes. Polyunsaturated fatty acids can influence membrane properties and cellular signaling. Because these compounds are continuously synthesized, transported, stored, and consumed, the shrimp lipid profile can change considerably during different physiological conditions.

Lipidome remodeling begins when shrimp alter the use of available nutrients. Dietary carbohydrates and proteins can contribute to energy metabolism, while dietary lipids provide fatty acids and other compounds required for cellular functions. When energy intake exceeds immediate metabolic requirements, some nutrients can be converted into lipid reserves. During periods of increased energy demand, stored lipids can be mobilized and converted into usable energy. This balance is particularly important in cultured shrimp because feed composition can directly influence lipid deposition and tissue composition.

The hepatopancreas is one of the most important organs associated with lipid metabolism in shrimp. It participates in digestion, nutrient absorption, storage, and metabolic regulation. Lipids absorbed from the digestive tract can be processed within this organ and distributed to other tissues. Changes in hepatopancreatic lipid composition can therefore provide useful information about nutritional condition. During periods of active growth, the hepatopancreas may accumulate particular lipid classes that support energy requirements and tissue development. During reproductive development, lipid movement can increase toward gonadal tissues, where lipids contribute to gamete development and embryonic energy supply.

Phospholipid remodeling is another important part of shrimp lipid biology. Cellular membranes must maintain an appropriate balance of fatty acids to preserve membrane structure and function. Temperature changes can influence membrane fluidity, and shrimp can modify the fatty acid composition of membrane phospholipids in response. At lower temperatures, increased proportions of certain unsaturated fatty acids may help maintain membrane flexibility. At higher temperatures, changes in membrane lipid composition can support appropriate physical properties of cellular membranes. These adjustments allow cellular processes to continue under changing environmental conditions.

Long-chain polyunsaturated fatty acids are especially relevant to shrimp nutrition. Compounds such as eicosapentaenoic acid and docosahexaenoic acid are associated with membrane function, cellular signaling, growth, and physiological regulation. Marine organisms often obtain these fatty acids directly from their diet or through limited metabolic conversion of precursor compounds. The availability of these fatty acids in formulated feeds can therefore affect the lipid composition of shrimp tissues. A feed containing appropriate lipid sources may contribute to suitable tissue lipid profiles and support normal physiological development.

Dietary lipid sources also produce different patterns of lipidome remodeling. Fish oils, algal oils, vegetable oils, animal-derived

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ingredients, and microbial oils contain different fatty acid combinations and lipid classes. When one lipid source is replaced by another, shrimp may alter the relative abundance of particular fatty acids within their tissues. Such changes can affect membrane composition, energy storage, and metabolic signaling. The response depends on shrimp species, developmental stage, feeding duration, feed composition, and environmental conditions.

Lipidomic analysis can provide a detailed picture of these metabolic responses. Traditional biochemical measurements generally quantify total lipid, triglycerides, cholesterol, or selected fatty acids. Lipidomic approaches can examine hundreds of individual lipid molecules at the same time. Mass spectrometry-based techniques are widely useful for this purpose because they can detect differences in molecular lipid species. Chromatographic separation combined with mass spectrometric detection can help distinguish lipid classes and molecular forms that may not be separated through conventional biochemical assays.

Data obtained from lipidomic analysis can be used to compare shrimp exposed to different diets or environmental conditions. For example, shrimp receiving different sources of dietary oils may show changes in phosphatidylcholine, phosphatidylethanolamine, triglyceride, lysophospholipid, and sphingolipid profiles. These differences can be evaluated together with growth rate, feed conversion, survival, tissue composition, and other physiological measurements. Such integrated analysis can help identify associations between feed composition and metabolic responses.

Disease and immune challenges can also produce liposome changes. When shrimp encounter microbial stress, energy allocation may shift toward immune-related processes. Lipids participate in cellular signaling and membrane restructuring during immune responses. Changes in specific phospholipids, free fatty acids, and signaling-related lipid molecules may therefore occur during infection or physiological stress. Lipidomic profiles could potentially assist researchers in identifying metabolic signatures associated with different health conditions. These profiles should be interpreted together with microbiological, molecular, histological, and physiological observations rather than being considered independently.

Molting represents another condition associated with substantial metabolic change. Shrimp periodically shed their exoskeleton and produce a new one. This process requires energy, mineral regulation, tissue restructuring, and coordinated physiological activity. Lipids stored in the hepatopancreas and other tissues can contribute to the energy requirements of molting. Changes in lipid abundance during different molting stages may therefore reflect shifts in energy demand and tissue metabolism. Monitoring lipid profiles across molt stages could improve understanding of how nutrition affects growth and survival.

Reproductive development also involves significant lipid redistribution. Mature females can transfer lipid reserves toward developing ovaries, where lipid-derived energy and structural components support oocyte maturation. The composition of ovarian lipids can differ from that of hepatopancreatic reserves because reproductive tissues have specific nutritional requirements. Studying these changes may assist broodstock nutrition research by identifying lipid profiles associated with reproductive performance, egg quality, and larval development.

Environmental conditions can modify lipid metabolism as well. Salinity changes require physiological adjustments related to osmoregulation, while temperature influences metabolic rate and membrane properties. Dissolved oxygen availability can affect energy metabolism and lipid utilization. Exposure to pollutants may also alter lipid synthesis, oxidation, and membrane composition. Lipidomics can therefore serve as a useful research approach for examining how environmental conditions influence shrimp physiology at the molecular level.

Shrimp lipidome remodeling is a dynamic process involving nutrient availability, tissue metabolism, environmental conditions, development, immunity, molting, and reproduction. Understanding these changes can improve the interpretation of shrimp nutritional requirements and metabolic health. Combining lipidomic measurements with growth data, feed analysis, water-quality records, molecular assays, and tissue observations can provide a broader assessment of shrimp physiology. Continued research into lipid pathways and molecular lipid profiles may also support the development of improved aquaculture feeds and more precise nutritional strategies for different production stages.

CONCLUSION

The study of shrimp lipidomes therefore offers a detailed perspective on how shrimp allocate and transform nutrients under changing biological conditions. Rather than examining total lipid content alone, researchers can investigate individual molecular lipid species and their relationships with physiological processes. This approach can contribute to a deeper understanding of shrimp metabolism and provide useful information for nutrition, broodstock management, health assessment, environmental studies, and sustainable aquaculture production.