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Perspective

Muscle Lipid Remodeling in Cultured Fish: Mechanisms and Influencing Factors

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DESCRIPTION

Fish muscle lipid remodeling is an important biological process that influences growth, energy storage, swimming performance, flesh quality, stress tolerance, and nutritional value in cultured fish. Muscle tissue is not simply a structural component responsible for movement. It is also an active metabolic tissue that continuously adjusts its lipid composition according to feed supply, environmental conditions, developmental stage, activity level, and physiological demand. Lipids within muscle cells occur mainly as membrane components and stored energy reserves. Their proportions and molecular composition can change when fish experience different dietary lipid sources, changes in temperature, altered feeding schedules, or periods of rapid growth. Understanding these changes can assist aquaculture nutrition research in developing feeding programs that support healthy growth while maintaining desirable flesh characteristics.

Muscle lipids include several classes of molecules with different biological functions. Triacylglycerol's are major storage lipids and can accumulate when dietary energy intake exceeds immediate metabolic requirements. Phospholipids are important components of cellular membranes and contain fatty acids that influence membrane structure and cellular signaling. Cholesterol participates in membrane organization and serves as a precursor for several biological molecules. Free fatty acids can be used as metabolic substrates or incorporated into other lipid molecules. The relative abundance of these compounds is influenced by the species, age, nutritional condition, muscle type, and environmental history of the fish.

Fatty acid composition is particularly important in muscle lipid remodeling. Saturated, monounsaturated, and polyunsaturated fatty acids perform different physiological functions. Long-chain polyunsaturated fatty acids are especially relevant because they contribute to membrane properties and participate in cellular signaling. Marine fish can obtain substantial quantities of certain long-chain fatty acids from marine-derived feed ingredients, while many freshwater species possess greater capacity for modifying shorter-chain precursors. However, this capacity differs considerably among species and may also change during development.

Diet is one of the strongest factors affecting muscle lipid composition in cultured fish. Modern aquafeed may contain combinations of fish oil, vegetable oils, algal ingredients, animal-derived lipids, and other lipid sources. Substitution of one lipid source for another can alter the fatty acid profile deposited in muscle. For example, increasing plant-derived oils may raise the proportion of certain C18 fatty acids while reducing the amount of some marine-associated long-chain polyunsaturated fatty acids. Fish can respond by modifying endogenous lipid metabolism through changes in fatty acid synthesis, elongation, desaturation, oxidation, and storage.

The process of lipid remodeling involves coordinated biochemical pathways. Fatty acids entering muscle cells may undergo oxidation in mitochondria to generate energy, become incorporated into phospholipids, or be converted into storage lipids. Enzymes involved in fatty acid elongation and desaturation can modify incoming substrates and create molecules with different chain lengths and degrees of unsaturation. Lipid transport proteins also influence the movement of fatty acids between tissues. As a result, the lipid profile measured in muscle represents the combined effect of dietary input, internal synthesis, transport, oxidation, and storage.

Energy balance has a major effect on these processes. During periods of abundant food intake, fish may increase the deposition of triacylglycerol's in muscle and other tissues. When food availability declines, stored lipids can be mobilized and oxidized to supply energy. Fasting therefore may reduce muscle lipid reserves, although the response differs among species. Refeeding can subsequently increase lipid deposition as fish restore energy reserves and resume rapid tissue growth. These changes are relevant to aquaculture because feeding interruptions, grading, transportation, spawning preparation, and seasonal changes can modify energy metabolism.

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Growth rate also affects muscle lipid remodeling. Young fish generally allocate substantial dietary nutrients toward protein synthesis and tissue formation, while larger fish may deposit greater quantities of lipid depending on feed composition and energy intake. Muscle fibers can differ in their metabolic properties, and lipid distribution may vary between white muscle and more oxidative muscle tissues. White muscle is primarily associated with short-duration activity, whereas oxidative muscle supports sustained swimming. Their metabolic characteristics can therefore influence how fatty acids are stored and utilized.

CONCLUSION

Fish muscle lipid remodeling is consequently a dynamic process controlled by interactions among nutrition, metabolism, environment, growth, and physiological demand. The muscle continuously adjusts its lipid stores and membrane composition in response to changing conditions. Studying these responses can improve knowledge of fish metabolism while supporting better feed formulation and product quality management. A detailed understanding of lipid deposition and fatty acid transformation can help aquaculture researchers design diets that supply energy efficiently, support normal physiological functions, and maintain valuable nutritional characteristics in edible fish muscle.