

From Feed to Fillet: How Mineral Nutrition Supports Quality, Resilience and Health in Aquaculture

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At first glance, the journey from aquafeed to fillet seems straightforward. A pellet is formulated, manufactured, delivered to the farm and consumed by fish or shrimp. Nutrients are digested, growth follows, and eventually the animal reaches harvest. But inside that apparently simple journey, thousands of microscopic biological decisions are taking place. Cells are defending themselves against oxidative pressure. Skin and mucosal barriers are responding to handling, water quality and pathogen pressure. Muscle tissue is developing. Antioxidant systems are being activated. Minerals, present in the diet in small quantities, are quietly influencing whether the animal remains resilient, and whether the final fillet meets the expectations of processors, retailers and consumers.

Aquaculture has moved far beyond nutrition for growth alone. Producers today are expected to deliver efficient performance, strong animals, good external quality, high survival during stressful production phases, high-value fillets and improved sustainability. This is particularly relevant as aquafeeds evolve towards more plant-based, alternative and circular raw materials, while the industry continues to face pressure to improve feed efficiency, reduce waste and support animal welfare.

In this context, mineral nutrition deserves renewed attention. Minerals are not simply background nutrients in a premix. They act as enzyme cofactors, structural components and regulators of antioxidant defense, immune function, epithelial integrity, connective tissue formation, osmoregulation and tissue repair. The central question is therefore not only how much mineral is present in the diet, but how much is available, absorbed, retained and used by the animal.

Mineral nutrition under modern production pressure

Modern aquaculture exposes fish and shrimp to a combination of biological and environmental stressors. Higher stocking densities, grading, vaccination, sea transfer, transport, handling, temperature variation, oxygen fluctuation and pathogen pressure can all increase physiological demand. At the same time, ingredient changes influence the natural supply and availability of trace minerals. Diets with higher inclusion of plant-based raw materials contain mineral-binding compounds and show greater variation in mineral contribution than traditional marine ingredients.

This means that formulating only on total mineral content is not sufficient. A mineral that is included in the feed but poorly absorbed has limited biological value. High inclusion of poorly available inorganic minerals can also increase antagonisms in the gut, where one mineral interferes with the absorption or utilization of another. The practical consequence is clear: precision mineral nutrition should focus on biological delivery, not just dietary addition.

Small nutrients with large biological roles

Trace minerals influence aquaculture performance through multiple interconnected pathways. Selenium is essential for selenoproteins, including glutathione peroxidases and thioredoxin reductases, which regulate redox balance and protect cells against oxidative damage. Zinc contributes to epithelial integrity, skin barrier function, wound repair, immune function and many enzyme systems. Copper is involved in connective tissue formation, antioxidant enzymes, pigmentation and immune function. Manganese plays roles in skeletal development, cartilage formation, metabolism and antioxidant processes.

Oxidative stress is not an abstract biochemical concept. In intensive aquaculture, it translates into cellular damage, weaker epithelial barriers, impaired immune responses and poorer tissue stability. Stressors such as crowding, hypoxia and nutritional transitions increase reactive oxygen species production and disturb cellular redox balance. Selenium, through its role in selenoproteins, is directly connected to antioxidant defense under these conditions.

Selenium: from antioxidant defense to fillet value

Among trace minerals, selenium has a particularly important role in aquaculture because it connects stress resilience, immunity and final product quality. Selenium supports the synthesis and function of selenoproteins involved in antioxidant defense and redox regulation. Under intensive production conditions, when fish are exposed to handling, environmental fluctuation or pathogen pressure, maintaining antioxidant capacity becomes critical.

The source of selenium matters. Exential Selenium 4000, based on highly pure L-selenomethionine, enables efficient incorporation into body proteins, creating a functional selenium reserve in tissues, including muscle. This reserve becomes particularly relevant during periods of stress, when metabolic demand for antioxidant capacity increases. In contrast to inorganic selenium sources, which primarily support immediate selenoprotein synthesis, L-selenomethionine allows storage and later mobilization, supporting a more consistent antioxidant response under fluctuating production conditions.

The difference in biological delivery between sources is substantial. In a 9-week seawater feeding trial with Atlantic salmon post-smolts, dietary selenium retention reached 58 to 61% with L-selenomethionine, compared to 30 to 38% when the same amount of selenium was supplied as sodium selenite. Apparent selenium availability showed a similar pattern: 68 to 72% for L-selenomethionine versus 26 to 27% for sodium selenite at equivalent inclusion levels. For fillet selenium specifically, the efficiency advantage for the organic source was nearly tenfold (slope ratio 9.74, $p < 0.0001$) (Prabhu et al., 2020, Aquaculture 526:735413). These differences translate directly into practice: more selenium reaches the animal's tissues, and less is excreted into the environment per kilogram of fish produced. This distinction is directly relevant as aquafeeds include more plant-based ingredients to replace fishmeal and fish oil, because selenium content in reformulated feeds can become lower or more variable. Exential Selenium 4000, based on highly pure L-

selenomethionine, delivers the tissue incorporation efficiency that inorganic sources cannot match. Selenium should not be viewed only as a trace nutrient in the premix; in aquaculture, it is part of the fish's antioxidant reserve, helping support performance, health and final product quality when production pressure increases.

Selenium also connects directly to fillet value. Fish fillets are rich in high-quality protein and valuable lipids, including long-chain omega-3 fatty acids in many species. These same nutritional qualities make fillet tissue vulnerable to oxidative processes that affect freshness, colour stability and lipid quality. By supporting antioxidant systems, selenium contributes to the protection of muscle tissue, and selenium deposition in edible tissue adds nutritional value to the final product.

Hydroxy trace minerals: precision support for skin and structural integrity

While selenium addresses the antioxidant dimension, broader trace mineral nutrition is essential for structural integrity and health. Skin is one of the most important defense organs in fish. It is not only an external covering; it is a living barrier that includes scales, mucus, epithelial cells, immune components and microbial interactions. When this barrier is compromised by handling, grading, vaccination, sea transfer, parasite pressure or mechanical damage, the animal must rapidly activate repair mechanisms. Poor skin condition can affect welfare, increase vulnerability to secondary challenges and reduce external quality at harvest.

Wound healing is biologically demanding. Tissue damage triggers inflammation and immune activation. An oxidative burst defends the damaged area, but also increases the need for antioxidant control. Cells then proliferate, collagen is deposited and connective tissue is rebuilt.

Trace minerals are involved at several points in this sequence. Zinc supports epithelial repair, immune cell function and enzyme activity. Copper contributes to connective tissue cross-linking and antioxidant enzymes. Manganese supports connective tissue metabolism and antioxidant processes. Together, these minerals support the biological capacity to maintain tissue integrity and respond to physical challenges. Hydroxy trace mineral sources improve the biological availability of zinc, copper and manganese compared to inorganic sulphate sources, through higher stability in feed and controlled solubility in the gut, which reduces mineral antagonism and improves delivery to target tissues. Excential SMART (Orffa Additives BV), providing zinc, copper and manganese in hydroxy form, is designed to support skin health and the biological capacity for tissue repair. This does not mean that mineral nutrition treats wounds directly. Wound healing remains influenced by water quality, pathogen pressure, handling procedures, stocking density, genetics and veterinary management. However, precision mineral nutrition can be part of the preventive foundation that helps fish maintain stronger barriers and better repair capacity before visible problems appear.

Fillet quality: the visible outcome of invisible nutrition

For processors and retailers, fillet quality is expressed in concrete, measurable outcomes: freshness, firmness, colour stability, nutritional value, processing yield and shelf-life potential. These outcomes are not created at harvest; they are built during the production cycle. Selenium contributes to antioxidant protection and selenium deposition in edible tissue, while zinc, copper and manganese support structural tissue integrity and enzyme systems involved in muscle and connective tissue metabolism.

By combining Excential Selenium 4000 with Excential SMART, mineral nutrition becomes connected to both sides of fillet value: protecting tissue against oxidative pressure and supporting the structural integrity behind firmness and processing quality.

A study in Atlantic salmon smolt evaluating organic and inorganic mineral premixes found that mineral source and inclusion level influenced fillet yield, fillet technical and nutritional quality, bone strength, skin morphology and organ mineralization, alongside higher selenium retention in the organic mineral group (Kokkali et al. 2023).

These findings support a broader view of mineral nutrition: its impact extends beyond deficiency prevention to tissue quality, welfare-relevant parameters and processing outcomes that matter to buyers downstream.

For aquafeed formulators, this creates a genuine opportunity to align mineral strategies with harvest quality and customer value, not only with growth targets.

Sustainability and environmental relevance

Sustainability in aquaculture is discussed mainly in terms of marine ingredient replacement, feed conversion and survival. Mineral nutrition belongs in that conversation. Higher selenium retention with L-selenomethionine means less selenium is excreted per kilogram of fish produced. For zinc, copper and manganese, improved bioavailability from hydroxy mineral sources supports more precise supplementation and reduces the excess inclusion that would otherwise pass through the animal unchanged.

The aim is not to overstate the contribution of minerals, but to recognize that precision mineral nutrition supports the responsible use of feed resources and connects animal health, product quality and environmental performance within a single strategy.

Building quality from the inside

Modern aquaculture is judged not only by the volumes that are produced, but by the quality, health, welfare and sustainability behind those volumes. Mineral nutrition may be a small part of the formulation on paper, but it has a large influence in biology. Selenium supports antioxidant defense and tissue selenium reserves. Zinc, copper and manganese, delivered as hydroxy minerals, support skin, barrier function, immune competence and structural integrity. Together, they shift the mineral nutrition conversation from deficiency prevention towards resilience and quality.

From the first feed intake to the final fillet, mineral decisions are quietly shaping outcomes.

References (available upon request)

Kokkali M, Sveen L, Larsson T, Krasnov A, Giakoukakis A, Sweetman J, Lyons P and Kousoulaki K (2023) *Optimisation of trace mineral supplementation in diets for Atlantic salmon smolt with reference to holistic fish performance in terms of growth, health, welfare, and potential environmental impacts*. *Frontiers in Physiology*, 14:1214987. doi: 10.3389/fphys.2023.1214987

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