MINERALS

Introduction

Minerals are inorganic substances that have many important functions in the animal body. They are required to maintain many metabolic processes and to provide material for major structures (e.g. bones, teeth, exoskeleton of crustaceans) of aquatic animals. They are also required for maintenance of osmotic pressure, acid-base balance (e.g., the regulation of blood pH, hemolymph, urine and other body fluids) and the proper functioning of muscles and nerves. Unlike carbohydrates, fats, and proteins, they do not provide energy but they may serve as components of enzymes, vitamins, and hormones. Fish, especially marine fish species, live in an environment that contains many of the minerals that they need for growth and survival.

This section discusses the macro, micro, and trace minerals; their physiologic functions; and deficiency signs and symptoms. It also gives a summary of the mineral functions and mineral requirements of fishes and shrimp.

Classification of Minerals

About 20 inorganic elements are required to meet the structural and metabolic functions of living organisms. They are grouped into macro, micro, and trace minerals.

The macrominerals calcium, phosphorus, magnesium, potassium, sodium and chlorine are required in the diet in relatively larger quantities than microminerals.

The microminerals are chromium, copper, cobalt, iron, iodine, manganese, molybdenum, selenium, and zinc. So far, trace minerals such as aluminum, arsenic, cadmium, lead, mercury, nickel, silicon, tin, and vanadium have no known function in fish.

General functions of minerals

The biochemical functions of minerals in aquatic animals are similar to those in land animals, with the exception of osmoregulation. Minerals may serve as components of hard-tissue matrices, soft tissues, metalloproteins, and as cofactors or activators of enzymes. The more soluble minerals (calcium, phosphorus, sodium, potassium, and chlorine) function in osmoregulation and in maintenance of acid-base balance and membrane potentials.

Unlike vertebrates, there are several physiological requirements unique to crustaceans, particularly in the molting cycle which is necessary in crustacean growth. Although some minerals are temporarily stored in the tissues, such as the hepatopancreas, a significant amount is lost during molting or ecdysis. A summary of functions of minerals is shown in Table 2.14.

Table 2.14 Summary of mineral functions

Mineral	Function and Essentiality
Calcium	Structural component of hard tissue; Co-factor for enzymatic processes; Muscle function and proper nerve impulse transmission; Osmoregulation
Phosphorus	Component of hard tissues and organic phosphates (e.g ATP, phospholipids, coenzymes, DNA and RNA); Buffer for the maintenance of normal pH of intra- and extra-cellular fluids
Potassium	Carbohydrate metabolism and protein synthesis; Osmoregulation; Acid-base balance; Phosphorylation reactions
Magnesium	Metabolism of fats, carbohydrates and proteins; Cellular respiration; Intra- and extracellular homeostasis; Phosphate transfer and thiamine pyrophosphate reactions; Osmoregulation
Copper	Functions in hematopoiesis and in numerous copper-dependent enzymes (e.g. cytochrome c oxidase, ferroxidase); Component of hemocyanin
Cobalt	Source for microbial synthesis of B_{12} in intestine
Iron	Heme containing enzymes (e.g. cytochromes, oxidases, peroxidase and catalases); Cofactor for enzymes; Hemoglobin
Iodine	Neuromuscular functions; Intermediary metabolism; Synthesis of thyroid hormones
Manganese	Cofactor of various enzyme synthesis
Selenium	Component of glutathione peroxidase
Zinc	Cofactor in several enzyme systems; Component of a large number of metalloenzymes

Source: Halver 1989

Mineral Availability

In general, bioavailability of minerals has been found to be positively correlated with their solubility in water. Highly soluble salts appear to be beneficial, but their leaching rates from diets have to be measured. In addition to inorganic sources, organic chelates and complexes of mineral elements are useful means of delivering minerals. Considering these limitations, water soluble inorganic salts or bioavailable organic salts are preferrable for use in mineral premixes.

Macrominerals

Calcium

Calcium is mostly found in the skeleton and scales of bony fish and in the exoskeleton of crustaceans. Fish scales are an important site of calcium metabolism and deposition. Aside from its structural function, calcium is important in physiological processes including metabolism, nerve and muscle contraction, nerve impulse transmission, maintenance of cell integrity, osmoregulation, and activation of important enzymes. Calcium and phosphorus deficiencies can cause soft-shelling in shrimps (Figure 2.15).

Figure 2.15
Calcium and phosphorus deficiencies. Soft-shelled shrimp mainly due to calcium and phosphorus deficiencies has caused losses in the shrimp industry.
Source: Lavilla 2001

Fish may totally or partially meet their calcium requirement through absorption of calcium from the water via their gills, fins and oral epithelia. The gills are the most important site of calcium regulation. Generally, calcium from feed ingredients for example, fish meal, may meet the requirements of most fish, however, it is a common practice to supplement the feed with calcium.

Phosphorus

Phosphorus is another major mineral required by fish and is an important constituent of nucleic acids and cell membranes. It is directly involved in the energy-producing cellular reactions and is a component of essential molecules such as adenosine triphosphate (ATP). Feed is the main source of phosphorus for fish because the concentration of phosphorus in natural waters is low. Consequently, the need for a dietary source of phosphorus is more critical than for calcium because fish must effectively absorb, store, mobilize, and conserve phosphate in both freshwater and seawater environments.

Most fish species require a dietary inclusion of 0.5% to 1.0% available phosphorus. Generally, phosphorus requirements are not affected by dietary calcium levels. In controlled experiments, the growth of both common carp and trout have been shown to be positively correlated with dietary phosphorus levels but not with calcium levels. The apparent phosphorus availability values for several phosphorus sources have been estimated. They are: calcium phosphate monobasic, 46%; calcium phosphate dibasic, 14%; calcium phosphate tribasic, 5.7%; sodium phosphate monobasic, 70%; and potassium phosphate monobasic, 68%. Dietary calcium and phosphorus are important in the prevention of soft-shelling in shrimps.

Sodium, potassium, and chlorine

Sodium, potassium, and chlorine are the most common inorganic elements found in fish. They are abundant electrolytes in the body and are essential for a number of physiological processes. Appropriate levels of these ions are required for proper functioning of cells and for maintaining nerve function. Fish readily absorb these elements from the aquatic medium, especially in marine waters, and the tissue levels of these ions are maintained as a result of osmoregulation. They are abundant in sea water and in common feedstuffs used in preparation of fish diets. Thus, dietary supplementation of these elements is normally not required.

Magnesium

A large proportion of magnesium in fish is contained in the skeletal tissue. Magnesium is an essential cofactor in many metabolic reactions. These enzymes include the phosphokinases, thiokinases, phosphatases, pyrophosphatases, and amino acyl synthetases. It is also needed in skeletal tissue metabolism, osmoregulation, and in maintaining muscle tone.

General symptoms of magnesium deficiency include reduced weight gain and poor feed conversion. In rainbow trout, magnesium deficiency leads to renal calcinosis and flexibility of the muscle, partly due to an increase in extracellular fluid volume. Most feed ingredients, especially those of plant origin, are abundant in magnesium thus, magnesium supplementation in practical diets is generally not required.

Microminerals

Copper

Copper is an important component of a number of metalloenzymes that are involved in a wide variety of metabolic processes. It is associated with cytochrome c oxidase of the electron transport chain in cells. It is the primary oxygen carrier in hemocyanin of crustaceans and molluscs. Fish appears to tolerate copper in the diet than dissolved copper from the water. Concentrations of 0.8-1.0 mg copper per liter in water are toxic to many fish species. Feed ingredients such as fish solubles, krill meal, and yeast contain relatively high levels of copper. Shrimp in general cannot meet their physiological requirement for copper from seawater. In white shrimp *Penaeus vannamei*, symptoms of deficiency include poor growth, reduced copper levels in the carapace, hepatopancreas and hemolymph, and enlargement of the heart.

Iron

Dietary iron is essential in fish for blood formation, maintaining normal hemoglobin content, hematocrit value, and cell size. A minimum dietary concentration of 150*ug* per gram diet is required to prevent iron deficiency resulting in hypochromic, microcytic anemia in red sea bream and common carp. Dietary iron deficiency has not been observed in shrimp. In contrast, dietary supplementation of shrimp feed with iron greater than 150*ug* per gram has been found to give poor growth. Since crustacean diets generally contain polyunsaturated fatty acids, excessive supplementation of ferrous iron in the diet may affect diet stability through increased lipid oxidation.

Manganese

Manganese is important either as a cofactor that activates metal-enzyme complexes or as an integral part of metalloenzymes in protein, carbohydrate, and lipid metabolism. The uptake of manganese from water by fish has been demonstrated but it is more efficiently absorbed from feed. However, due to the potential inhibitory effects of phytic acid on the bioavailability of manganese, feed supplementation may be desirable. Dietary deficiencies in fish have resulted in poor growth, skeletal abnormalities, embryo mortalities, and poor hatching rates.

Selenium

Selenium is an integral component of the enzyme glutathione peroxidase that protects cells and membranes from deleterious effects of peroxides. In conjunction with vitamin E, this enzyme functions as a biological antioxidant which protects biological membranes against lipid peroxidation. Selenium imparts a protective effect against the toxicity of heavy metals such as cadmium and mercury. The selenium requirement of fish varies with the polyunsaturated fatty acid and vitamin E content of the diet. Both selenium and vitamin E are required to prevent muscular dystrophy in Atlantic salmon. In general, practical diets containing fish meal contains adequate amount of selenium and does not require supplementation.

Zinc

Zinc is an integral component of metalloenzymes including dehydrogenases, aldolases, peptidases, and phosphatases. Approximately 20 different enzymes has been found to contain zinc. Many metabolic functions are affected by zinc deficiency. Fish can accumulate zinc from both water and feed but dietary zinc is more efficiently absorbed. Practical diets contain feedstuffs that are good sources of zinc; for example, fish meal. However, zinc bioavailability is generally very low, thus supplementation is essential. Feedstuffs that are relatively high in phytate may further reduce zinc bioavailability. Cataract is a common symptom of zinc deficiency in fish (Figure 2.16).

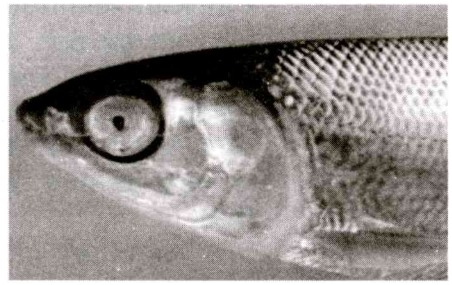

Figure 2.16
Zinc deficiency cataract: non-availability of zinc due to high levels of calcium and phosphorus in fish feed has caused losses in the fish farming industry.

Trace minerals

Information on the dietary requirements of other microminerals is limited. A number of trace elements are required for adequate fish nutrition but their dietary deficiencies have not been reported. Cobalt acts as a component of vitamin B_{12}. Sulfur is required for the synthesis of cysteine. Chromium is important in normal glucose and lipid metabolism.

Mineral Supplementation of Practical Fish Diets

Although the dietary mineral requirements of fish have not been well established, practical diets are usually supplemented with a mineral premix. Practical diets may normally contain substantial amounts of endogenous minerals, thus a complete mineral premix may not be necessary. Excessive mineral supplementation increases the cost of feed and may reduce the bioavailability of other minerals and increase phosphorus pollution. Many commercial feed binders may also contain high levels of calcium and magnesium that may reach undesirable levels of these minerals in the feed.

Most studies on the mineral requirements of fish have been conducted using semipurified diets. Dietary requirements are determined by feeding graded levels of the element being studied and measuring the physiological response of the test animal. Minerals required by fish are calcium, magnesium, phosphorus, and micro elements such as copper, iodine, iron, manganese, selenium and zinc. In general, the dietary requirements for minerals are poorly understood because of the difficulty in devising mineral-deficient diets and the need to deplete tissue mineral stores.

Mineral Requirements of Fish

Although inorganic elements are required for the normal life processes of fish, knowledge of their mineral nutrition is still one of the least known areas of fish nutrition. Unlike other nutrients, significant amounts of minerals can be absorbed from their external environment thus it is difficult to control the dietary intake of the mineral being studied. Calcium, sodium, potassium, iron, zinc, copper and selenium are generally derived by fish from the rearing water. The exchange of ions from the surrounding water across the gills and skin of fish complicates the measurements of mineral requirements. Interaction between minerals further complicates the assessment of dietary requirements. So far, there is very limited information on the dietary requirements for minerals by fish.

A summary of the known dietary mineral requirements of various fish species is presented in Table 2.15 and their deficiency symptoms are summarized in Table 2.16.

Table 2.15 Summary of the mineral requirements of various fish and shrimp species

Mineral	Channel catfish	Common carp	Japanese eel	Nile tilapia	Rainbow trout	Kuruma shrimp	Tiger Shrimp
Ca			0.27%			1.0-2.0%	1.0%
P	0.33-0.45%	0.6 - 0.7 %	0.58 %	0.8-1.0 %	0.7-0.8 %	1.0-2.0%	1.0%
Mg	0.04 %	0.04-0.05%	0.04 %	0.05-0.07 %		0.30%	
Cu	3μg/g			3 - 4μg/g	3μg/g		
Fe		150μg/g	170μg/g				
Mn		13μg/g	13μg/g	12μg/g			
Zn	20μg/g	15-30μg/g		10μg/g	15-30μg/g		

Source: Watanabe et al. 1988; Bautista and Baticados 1988

Table 2.16 Mineral deficiency symptoms in fish and shrimp

Minerals	Deficiency symptoms
Ca	Poor growth in channel catfish; Soft-shell syndrome in crustaceans
P	Poor growth & skeletal abnormality in common carp & rainbow trout; Low feed efficiency and high lipid content in common carp; Low ash in whole body and vertebrate in common carp, rainbow trout and channel catfish
Mg	Poor growth and high mortality in common carp and rainbow trout; Sluggishness and convulsion in common carp, rainbow trout and channel catfish; High Ca content in bone of carp and rainbow trout; Anorexia in channel catfish; Skeletal abnormalities and renal calcinosis in rainbow trout
Cu	Poor growth in common carp and rainbow trout; Dwarfism in Japanese eel
Co	Poor growth in common carp
Fe	Anemia in common carp
I	Dwarfism in Japanese eel
Al	Dwarfism in Japanese eel
Zn	Poor growth, high mortality, erosion of fins and skin, low Zn and Mn content in bone of common carp and rainbow trout; Dwarfism in rainbow trout and Japanese eel; Cataract in rainbow trout; Low Ca, Mg and P and high mortality in common carp; Low Zn and Mn in common carp and rainbow trout

Source: Watanabe et al. 1988

Guide Questions

1. What are minerals?
2. What are the 3 groups of minerals? Give examples of each group.
3. What are the general functions of minerals?
4. What mineral is needed for normal formation of bones, scales and teeth in fish?
5. What element is a component of thyroid hormones? of metalloenzymes?
6. What mineral is a component of vitamin B_{12}?
7. What mineral protects biological membranes against lipid oxidation?
8. What minerals are important to prevent soft-shelling in shrimps?
9. Why is the need for a dietary source of phosphorus more critical than for calcium?
10. What mineral is a component of glutathione peroxidase?
11. What minerals are needed for blood formation in fish? hemocyanin formation in mollusks and crustaceans?
12. What is the consequence of iron deficiency in fish?
13. Why is mineral nutrition of fish one of the least known areas of fish nutrition?

Summary

Proteins and amino acids

Amino acids are the basic unit of proteins and have a general structure with an amino group ($-NH_2$) and a carboxyl group ($-COOH$) bonded to the alpha-carbon atom. The nature of the side chain, referred to as the R groups, are the basic differences among amino acids. The amino acids are divided into two groups: the dispensable or non-essential amino acids and the indispensable or essential amino acids. Of the 20 naturally occurring amino acids, ten are essential because they cannot be made by the fish or cannot be made in amounts that satisfy the requirement. These are: arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. The non-essential amino acids can be made by the animal from carbon and nitrogen precursor compounds. Cysteine (which can replace part of methionine) and tyrosine (which can replace part of phenylalanine), glycine, glutamic acid, glutamine, aspartic acid, asparagine, alanine, proline, and serine are non-essential amino acids.

Proteins are polymers of amino acids joined by peptide bonds. The structure of proteins is complex, with no obvious regular structure. To facilitate structure determination, it is customary to define four levels of organization. Primary structure is the order in which the amino acids are covalently linked together. Secondary structure is the hydrogen bonded arrangement of the polypeptide chain. Tertiary structure includes the three dimensional arrangement of all the atoms in the protein.