9

Vitamins

Vitamins are organic compounds, distinct from amino acids, carbohydrates, and lipids, that are required in trace amounts from an exogenous source (usually the diet) for normal growth, reproduction, and health. Vitamins are classified as water-soluble and fat-soluble. Eight of the water-soluble vitamins are required in relatively small amounts, have primarily coenzyme functions, and are known as the vitamin B complex. Three of the water-soluble vitamins, choline, inositol, and vitamin C, are required in larger quantities and have functions other than coenzymes. Vitamins A, D, E, and K are the fat-soluble vitamins that function independently of enzymes or, in some cases such as vitamin K, may have coenzyme roles. In mammals, the absence of vitamins leads to characteristic deficiency diseases, but in aquatic species such diseases are less specifically identified. Vitamin deficiency signs reported in fish and shrimp are listed in Table 9-1.

Some vitamins may be synthesized from other essential nutrients to spare a portion of the dietary requirement. For example, channel catfish (*Ictalurus punctatus*) appear to synthesize choline if adequate methyl donors such as methionine are present in the diet; however, if the concentration of dietary methionine is limiting, a choline requirement can be demonstrated (Wilson and Poe, 1988). An exogenous source of some water-soluble vitamins for certain warmwater fish has been shown to be derived from microorganisms in the gastrointestinal tract (Limsuwan and Lovell, 1981; Lovell and Limsuwan, 1982; Burtle and Lovell, 1989; Shiau and Lung, 1993a). In coldwater carnivorous fish, microorganisms are not a significant source of vitamins (Hepher, 1988).

Both qualitative and quantitative vitamin requirements of fish and shrimp have been determined by feeding chemically defined diets deficient in a specific vitamin. The quantitative requirements for most of the vitamins have been established for Chinook salmon (*Oncorhynchus tshawytscha*), rainbow trout (*Oncorhynchus mykiss*), common carp (*Cyprinus carpio*), channel catfish, hybrid tilapia (*Oreochromis niloticus* × *O. aureus*), and yellowtail (*Seriola lalandi*). Qualitative requirements have been identified in several other species. Some shrimp, including tiger shrimp (*Penaeus monodon*), Kuruma shrimp (*Marsupenaeus japonicus*), fleshy prawn (*Fenneropenaeus chinensis*), Pacific white shrimp (*Litopenaeus vannamei*), *Farfantepenaeus californiensis*, and Indian white prawn (*Fenneropenaeus indicus*), have been studied to some extent regarding their vitamin requirements, of which tiger shrimp is the species that all the 15 required vitamins have been established. The requirements are affected by size, age, and growth rates as well as by various environmental factors and nutrient interrelationships. Thus, different researchers have reported fairly wide ranges in requirement values for growth in the same species. Growth performance may not be the only parameter for determining vitamin requirements in fish and shrimp. Other parameters, such as lipid accumulation, skeleton deformities, activity of specific enzymes, tissue vitamin storage, absence of deficiency sign, liver lipid content, hepatosomatic index, lipid oxidation degree, heat shock protein, and immune responses, have also been used for quantifying vitamin requirements of aquatic animals (Tables 9-2, 9-3, and 9-4).

FAT-SOLUBLE VITAMINS

The fat-soluble vitamins, A, D, E, and K, are absorbed in the intestine along with dietary fats; therefore, conditions favorable for fat absorption also enhance the absorption of fat-soluble vitamins. As fish seem to lack a lymphatic system as found in mammals, lipid and fat-soluble vitamins most likely are transported to the peripheral tissues via the portal vein and the liver. Animals store fat-soluble vitamins, either actively in specific cell compartments or by simple accumulation in the lipid compartment, if dietary intake exceeds metabolic needs. Thus, animals can accumulate enough fat-soluble vitamins in their tissues to produce a toxic condition (hypervitaminosis). This has been demonstrated in the laboratory with trout for vitamins A, D, and E, but it is unlikely to occur under practical conditions (Poston et al., 1966; Poston, 1969a; Poston and Livingston, 1969).

TABLE 9-1 Historical Vitamin Diagnostic Signs Reported in Fish and Shrimp (in alphabetical order)

Deficiency Signs	Vitamins	Species
Abnormal swimming (ataxia)	Riboflavin	Salmonids, channel catfish
	Pantothenate	Japanese eel
	Niacin	Japanese eel
	Biotin	Japanese eel
	C	Channel catfish, Korean rockfish, *Clarias* hybrid catfish
Ascites	A	Salmonids
	E	Salmonids
	C	Salmonids
Black death syndrome	C	Tiger shrimp, Pacific white shrimp, fleshy prawn, Kuruma shrimp, giant river prawn, blue shrimp
Congested fin, skin, or bronchial mantles	E	Yellowtail
	Thiamin	Yellowtail, Japanese eel, red sea bream
	Pantothenate	Japanese eel
	B_{12}	Yellowtail
	Folate	Yellowtail
Dark skin coloration	A	Yellowtail
	E	Yellowtail, hybrid striped bass
	Thiamin	Channel catfish, yellowtail
	Riboflavin	Salmonids, yellowtail, hybrid striped bass
	Biotin	Japanese eel, Indian catfish, African catfish
	Inositol	Salmonids, yellowtail
	Folate	Salmonids, Japanese eel
	Choline	Yellowtail
	C	Yellowtail, Korean rockfish, Mexican cichlid
Decreased liver lipid	Choline	Hybrid tilapia, red drum
Deformities (spinal, jaws, or snout)	A	Jian carp
	Riboflavin	Salmonids
	Niacin	Channel catfish, hybrid tilapia
	C	Channel catfish, yellowtail, olive flounder, Korean rockfish, Indian catfish, parrotfish, Asian sea bass, *Clarias* hybrid catfish, Mexican cichlid
Dermatitis	Riboflavin	Japanese eel
	Pantothenate	Japanese eel
Edema	A	Salmonids, channel catfish
	E	Salmonids
	Niacin	Salmonids, hybrid tilapia
Emaciation	Riboflavin	Common carp
	Pantothenate	Channel catfish
Erosion	A	Grouper
	Riboflavin	Yellowtail, blue tilapia, rainbow trout
	Pantothanate	Channel catfish
	Inositol	Salmonids
	C	Channel catfish, Japanese eel, hybrid tilapia, Indian catfish, Asian sea bass, *Clarias* hybrid catfish Japanese sea bass, Mexican cichlid
Exudative diathesis	E	Channel catfish
Eye pathological changes (iritis, cataract)	A	Salmonids
	Riboflavin	Yellowtail, salmonids, channel catfish, hybrid striped bass
	C	Olive flounder, Mexican chichlid
Gill pathological changes (clubbed gill; hyperplasia of the epithelial cells of gill lamellae; degenerative gill lamellae; distorted gill filaments)	Pantothenate	Salmonids, channel catfish, yellowtail, blue tilapia
	Biotin	Salmonids
	C	Salmonids

continued

TABLE 9-1 Continued

Deficiency Signs	Vitamins	Species
Hematological index changes (anemia; abnormal erythrocyte; reduced erythrocyte fragility value; reduced hematocrit value; megaloblastosis; misshapen nuclei in a small proportion of erythrocyte; low thrombocyte counts; higher hemocytoblast and neutrophil count; fragmented erythrocytes; prolonged blood clotting)	A	Yellowtail, rainbow trout
	E	Salmonids, Indian major carp, hybrid striped bass
	K	Salmonids, fleshy prawn
	Pyridoxine	Salmonids, common carp, Indian catfish
	Pantothenate	Salmonids, channel catfish, common carp, yellowtail, blue tilapia
	Niacin	Salmonids, channel catfish, common carp, Japanese eel, Indian catfish
	Folate	Salmonids, channel catfish, rainbow trout
	B_{12}	Salmonids, yellowtail, Indian major carp
	Inositol	Salmonids
Hemorrhage	A	Channel catfish, common carp, yellowtail, hybrid striped bass, Atlantic halibut, grouper, Jian carp, rainbow trout
	E	Channel catfish
	K	Salmonids, channel catfish
	Thiamin	Common carp, Japanese eel, red sea bream
	Riboflavin	Salmonids, common carp, Japanese eel
	Pantothenate	Common carp, Japanese eel, Jian carp
	Niacin	Common carp, yellowtail, Japanese eel, hybrid tilapia, Indian catfish
	Biotin	Yellowtail
	Choline	Salmonids, channel catfish
	C	Salmonids, yellowtail, Japanese eel, hybrid tilapia, olive flounder, Korean rockfish, *Clarias* hybrid catfish, Mexican cichlid
Hyperirritability (irritability)	Thiamin	Salmonids
	Riboflavin	Tiger shrimp
	Pyridoxine	Salmonids, channel catfish
	Pantothenate	Tiger shrimp
	Biotin	Channel catfish
Increased liver lipid (fatty liver; lipid infiltration of liver)	D	Salmonids, rainbow trout
	E	Channel catfish
	Biotin	Salmonids
	Choline	Salmonids, channel catfish, common carp, hybrid striped bass
	Inositol	Grouper, hybrid tilapia, tiger shrimp
Lesion	A	Salmonids
	Pyridoxine	Red hybrid tilapia
	Niacin	Salmonids, channel catfish, yellowtail, hybrid tilapia, common carp, rainbow trout
	Biotin	Salmonids
Lethargy (sluggishness; listlessness; sluggish movement; motionless)	A	Jian carp
	Riboflavin	Salmonids, Japanese eel, blue tilapia, parrotfish
	Pyridoxine	Yellowtail, red hybrid tilapia, Indian catfish
	Pantothenate	Common carp, blue tilapia
	Niacin	Channel catfish, Indian catfish
	Biotin	Common carp, yellowtail, Indian catfish
	Folate	Salmonids, channel carp
	Inositol	Yellowtail
	C	Salmonids, Pacific white shrimp
Lordosis	E	Common carp, grass carp
	C	Channel catfish, yellowtail, Indian catfish, red drum, Japanese sea bass
Loss of equilibrium	Thiamin	Salmonids, channel catfish
	C	Red drum
Loss of scale	C	Mexican cichlid
Mucosa (increase number of dermal mucous cells; loss of skin mucosa)	Biotin	Common carp
	Inositol	Common carp
Muscle dystrophy (muscular weakness)	Vitamin E	Salmonids, channel catfish, common carp, Korean rockfish, grass carp
	Niacin	Salmonids

TABLE 9-1 Continued

Deficiency Signs	Vitamins	Species
Organ pathological changes (pancreatic atrophy; kidney and pancreatic degeneration; anterior kidney necrosis; histopathological changes in liver, kidney, and intestine; atrophied pancreatic acinar cell; vacuolization of hepatic cell; white-grey intestine; severe atrophy of liver)	E	Channel catfish, common carp
	Riboflavin	Common carp
	Pyridoxine	Indian major carp, rainbow trout, gilthead sea bream
	Pantothenate	Salmonids
	Biotin	Salmonids
	Choline	Common carp
	Inositol	Japanese eel
	C	Parrotfish, Pacific white shrimp
Poor appetite (anorexia)	A	Hybrid striped bass, Jian carp, common carp
	Riboflavin	Channel catfish, hybrid striped bass, blue tilapia
	Pyridoxine	Hybrid tilapia, red hybrid tilapia, Indian catfish
	Pantothenate	Jian carp, parrotfish
	Niacin	Channel catfish, Indian catfish
	Biotin	African catfish
	B_{12}	Japanese eel
	C	Olive flounder, Korean rockfish, parrotfish, yellowtail
Reduced bone collagen	C	Channel catfish
Scoliosis	C	Salmonids, channel catfish, yellowtail, olive flounder, Korean rockfish, red drum, Japanese sea bass, Mexican cichlid
Short-body dwarfism (higher condition factor)	Riboflavin	Channel catfish, red hybrid tilapia, blue tilapia
	C	Indian catfish
Skin depigmentation	A	Salmonids, channel catfish, common carp, Jian carp
	E	Salmonids, channel catfish
	Thiamin	Common carp
	Riboflavin	Blue tilapia, rainbow trout, tiger shrimp
	Biotin	Channel catfish
	C	Pacific white shrimp
Swollen abdomen (distended abdomen)	Inositol	Salmonids
	C	Mexican cichlid
Tetany (nervous disorders; nervousness; spastic atrophy; spasms; convulsion)	D	Salmonids, rainbow trout
	Thiamin	Salmonids, channel catfish, common carp
	Pyridoxine	Salmonids, channel catfish, common carp, yellowtail, Japanese eel, red hybrid tilapia
	Pantothenate	Gilthead sea bream, Indian catfish
	Biotin	Parrotfish
	E	Salmonids, Indian catfish, African catfish, yellowtail
Twisted gill opercula	A	Common carp, yellowtail, rainbow trout
	E	Korean rockfish
	Pantothenate	Salmonids
	C	Mexican cichlid

Because fat-soluble vitamins can be stored in the body, the nutritional history of experimental fish prior to their use in requirement studies becomes critical. The time required to deplete fish of their stored fat-soluble vitamins is highly variable. Differences in vitamin intake prior to an experiment may be responsible for some of the conflicting findings on the induction and severity of deficiency signs.

Vitamin A

Vitamin A is crucial in a number of physiological processes necessary for optimal function of an animal. It is involved in cell differentiation, and hence is vital for reproduction as a key factor in embryo development; for development of epithelial cells from stem cells to fully functional layers, including mucus-producing cells; and proper differentiation of immune cells in response to exposure to pathogens or foreign proteins. Its function in vision is well established. The mechanisms of action of vitamin A are not equally well established for other functions. However, retionoic acid, bound to retionoic acid receptors in the nucleus, is a key factor in expression of genes involved in cell differenciation. Exessive intake of vitamin A, in the range of 5–10 times the requirement, may disturb the same functions as for which it