Chapter 16

Potential Role of Dietary Minerals in Fish and Crustaceans

T. Muralisankar, K. Mohan, V. Udhayakumar, and B. Balamuralikrishnan

Abstract Minerals are essential nutrients that play a key role in all living organisms. Minerals act as a catalyst for many biological functions of organisms including skeletal formation, maintenance of colloidal systems, acid-base equilibrium, and other biologically important compounds like enzymes, hormones, vitamins, etc. Aquatic animals can obtain essential minerals from diet and water. However, the quantitative requirement of each dietary mineral is species dependent. The quantitative requirement of dietary minerals has attained significant improvements in the aquaculture industry, particularly in fish and crustaceans. The adequate level of essential dietary minerals like calcium, potassium, sodium, iron, zinc, copper, selenium, etc., can promote survival, growth, proximate composition, nonspecific immunity, and disease resistance against the pathogen in fish and crustaceans. Regarding this, the optimum dietary requirement of minerals in fish and crustaceans has been studied and reported by earlier researchers. This chapter deals on the role of 11 dietary minerals such as calcium, magnesium, potassium, phosphorus, sodium, copper, chromium, fluorine, iron, selenium, and zinc) on survival, growth, feed index, digestive enzymes, proximate composition, immune response, antioxidants and disease resistance of fish and crustaceans.

Keywords Minerals · Survival · Growth · Fish · Crustaceans · Immunity · Disease resistance

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16.1 Introduction

Aquaculture is one of the largest food production sectors in the world next to agriculture which provides food security and blue economy of the nations. Fish and shellfish are the most valuable edible species which supply nearly 50% of total animal protein (FAO 2020). Globally, 82,095 thousand tonnes of fish and shellfish species were produced during 2018 which includes 54,279, 9387, 17,511, and 919 thousand tonnes of fish, crustaceans, mollusks, and other species, respectively (FAO 2020). Inland culture fisheries like fish and crustaceans are one of the major components in the world fish trade. Feed is one of the major components in the production of fish and crustaceans which accounts for nearly 50% of total fish production cost (Adikari et al. 2017). The feed which has an adequate level of nutrients like protein, lipid, essential amino acids, fatty acids, pigments, vitamins, and minerals is considered as the quality diet for aquaculture production. Minerals are a crucial and minimum requirement to secure the optimal health and growth of all living organisms. Aquatic animals including fish, crustaceans, and mollusks can acquire minerals from the diet and water currents. Absorption and functional forms of the minerals are maintained constantly for normal cellular metabolic functions. This is facilitated by the homeostatic mechanisms operating in the animal and creating to the fluctuations in nutritional intake. The dietary source of 20 minerals has been demonstrated as essential for animals including fishes and crustaceans. Among these, calcium, potassium, sodium, magnesium, chlorine, phosphate, and sulfur are macro minerals and zinc, copper, iron, selenium, chromium, cobalt, fluorine, iodine, manganese, molybdenum, nickel, silicon, tin and vanadium are trace minerals (Underwood 1963; Davis and Gatlin 1996; Hasan 2001; Goopla 2006; NRC 2011; Antony Jesu Prabhu et al. 2016).

Minerals are responsible for the skeletal formation, balancing of osmotic pressure, maintenance of colloidal systems, nerve impulse, muscle impulse, regulation of acid-base equilibrium and also serving as an essential component for vitamins, pigments, enzymes, hormones, production of blood cells, and antioxidants, etc. in aquatic animals (FAO 1987; Watanabe et al. 1997; Lall 2002). The biological role of minerals in fish, crustaceans, and other animals is given in Table 16.1. Earlier research findings reported that the minerals such as calcium, sodium, potassium, phosphorus, magnesium, zinc, iron, copper, and selenium have been identified and recommended as an essential dietary component for growth, normal physiological process, immune system, tolerance to stress, and disease resistance against pathogens in fish (Davis and Gatlin 1996; Keshavanath et al. 2003; Sudhakar et al. 2009; Yu et al. 2013; Liang et al. 2018; Neamat-Allah et al. 2019; Mondal et al. 2020; Musharraf and Khan 2020; Siqwepu et al. 2020; Afshari et al. 2021; Zhang et al. 2021) and crustaceans (Davis et al. 1993a, b; Lee and Shiau 2002; Cheng et al. 2005a; Ambasankar et al. 2006; Roy et al. 2007a; Nugroho and Fotedar 2013; Muralisankar et al. 2015; Srinivasan et al. 2016). Figure 16.1 depicts the role of dietary minerals on fish and crustaceans. Dietary mineral requirement studies normally engage the experiments where animal responses or performance

Table 16.1 Biological roles of minerals in fish and crustaceans

Mineral	Biological role	References
Calcium (Ca)	Calcium is a vital component for bone, crucial for normal blood clotting, formation of crustacean exoskeleton, and activator of many important enzymes (ATPases, pancreatic lipase, cholinesterase, succinic dehydrogenase, and acid phosphatase). Ca promotes cobalamin absorption in the gastrointestinal tract and regulates normal heartbeat. Ca is crucial for ionic regulation of fish as it influences the biological membranes permeability by preventing diffusive efflux and high ionic loss to water	FAO (1987), Wood and McDonald (1988), Lall (2002)
Phosphorus (P)	Plays a central role in energy and cell metabolism, it is an essential bone component, gristle, and exoskeleton of crustaceans. P is a component of phosphoproteins, nucleic acids, phospholipids, creatine phosphate, higher energy phosphate esters hexose phosphates, and key enzymes. P regulates the acid-base balance of fluids	FAO (1987), Kreisberg (1977), Håglin (2001), Lall (2002)
Potassium (K)	Potassium is a major cation of intracellular fluid which regulates normal intracellular acid-base balance and osmotic pressure. K is essential for breakdown of glucose in metabolism, protein and glycogen synthesis	FAO (1987), Marshall and Bryson (1998), Shiau and Lu (2004), Evans et al. (2005)
Sodium (Na)	Like potassium, sodium is also a main monovalent ion of extracellular fluids and plasma. Although the principal role of Na in animals is maintenance of acid-base balance, and the regulation of osmotic pressure. Na also essential for carbohydrate absorption	FAO (1987), Shiau and Lu (2004)
Chlorine (Cl)	Chlorine is important for the regulation of acid-base balance and osmotic pressure. Cl plays a unique role in oxygen and carbon dioxide transport in the erythrocytes and the maintenance of pH in digestive juice	FAO (1987), Costa et al. (2012)
Magnesium (Mg)	Magnesium is a necessary component of bone and cartilage of fish, and the exoskeleton of crustaceans. Mg is an activator of several key enzyme including mutases, kinases, muscle ATPases, alkaline phosphatase, cholinesterase,, enolase, isocitric	FAO (1987), Lall (1989), Nielsen (1990a), Davis and Gatlin (1996), Shivakumar and Kumar (1997), Lall (2002), Tam et al. (2003), Vormann (2003)

(continued)

Table 16.1 (continued)

Mineral	Biological role	References
	dehydrogenase, arginase, glutaminase, and deoxyribonuclease. Mg involved in intracellular acid-base balance regulation, stimulates muscle and nerve irritability. It also plays an essential role in metabolism of proteins, lipids, and carbohydrates. Mg also plays a key role in antioxidation and immunity mechanisms	
Sulfur (S)	Sulfur is an important element of several key amino acids (cystine and methionine), vitamins (biotin and thiamine), insulin, and the exoskeleton of crustaceans. Enzymes like glutathione and coenzyme A activities are depending on free sulfhydryl groups. S involved in the detoxification of aromatic compounds in animals	FAO (1987), Murthy and Gatlin (2006)
Iron (Fe)	Iron is one of the crucial elements of the respiratory pigments hemoglobin and myoglobin. Fe is an essential component of various enzyme systems including the catalases, cytochromes, peroxidases, xanthine, succinic dehydrogenase, and aldehyde oxidase. Fe is vital for transporting of oxygen and electrons	Robbins and Pederson (1970), FAO (1987), Watanabe et al. (1997), Lall (2002)
Zinc (Zn)	Zinc is an essential element of more than 80 metalloenzymes, including glutamic dehydrogenase, carbonic anhydrase, alcohol dehydrogenase, superoxide dismutase, alkaline phosphatase, pyridine nucleotide dehydrogenase, pancreatic carboxypeptidase, tryptophan desmolase, etc. Zn also serves as a cofactor in many enzyme systems like enolase, arginase, oxalacetic decarboxylase, and peptidases. Zn plays a vital role in metabolism of protein, lipid, and carbohydrate. It is being particularly active in the synthesis and metabolism of nucleic acids (RNA) and proteins. Zn has wound healing properties and associated with prostaglandin metabolism and structural role in nucleoproteins	FAO (1987), Watanabe et al. (1997), Lall (2002)

(continued)

Table 16.1 (continued)

Mineral	Biological role	References
Copper (Cu)	Copper is main component of numerous oxidation reduction enzymes, such as cytochrome c oxidase, superoxide dismutase, uricase, tyrosinase, caeruloplasmin, amine oxidase, and lysyl oxidase. It is intimately involved in iron metabolism, hemoglobin synthesis, and erythrocytes production. It is believed that Cu is necessary for the formation of the pigment melanin, formation of bone and connective tissue, and maintaining the integrity of the myelin sheath of nerve fibers. Cu is also involved in metabolism of normal connective tissue	O'Dell (1976), Lall (1977), FAO (1987), Davis (1987), Turnlund (1994), Watanabe et al. (1997), Lall (2002)
Manganese (Mn)	Manganese is essential element for activating the enzymes such as phosphate dehydrogenases and phosphate transferases. Mainly the enzymes concerned with the citric acid cycle including alkaline phosphatase, arginase, and hexokinase. Mn is an essential component of the enzyme pyruvate carboxylase. It also essential for regeneration of erythrocytes, bone formation, carbohydrate metabolism, etc.	FAO (1987), Watanabe et al. (1997), Lall (2002)
Nickel (Ni)	Nickel is essential for normal biological functions and plays a key role in the processes related to the vitamin B_{12}-dependent pathway in methionine metabolism	Uthus and Poellot (1996), Barceloux and Barceloux (1999), Phipps et al. (2002)
Cobalt (Co)	Cobalt is a vital component of vitamin B_{12}, and as such is essential for formation of erythrocytes and nerve tissues maintenance	Sherrell and Percival (1984), FAO (1987)
Selenium (Se)	Selenium is an essential component for the growth and maintenance of homeostatic functions and the enzyme glutathione peroxidase. Se with the vitamin E defenses the cellular tissues and membranes against reactive oxygen species (oxidative damage). Se participates in the biosynthesis of ubiquinone (coenzyme Q) which involves in cellular electron transport. Se also has influence on vitamin E absorption and retention. Se plays an important role in the normal functioning of the immune system, cellular immune response, and helping the body to resist viral infection	FAO (1987), NRC (2011), Köhrle et al. (2000), Rayman (2000), Lall (2002), Lin and Shiau (2005)

(continued)

Table 16.1 (continued)

Mineral	Biological role	References
Chromium (Cr)	Chromium has a crucial role in metabolism of carbohydrate (glycogen synthesis) and trivalent Cr (Cr^{3+}) is believed to play a significant role in metabolism of amino acids and cholesterol. Cr is an integral factor of the glucose tolerance and acts as a cofactor for the hormone insulin. Cr plays a crucial role in the nutritional and physiological responses of fishes	FAO (1987), NRC (2011), Küçükbay et al. (2006), Liu et al. (2010b)
Iodine (I)	Iodine is an essential component for biosynthesis of thyroid hormones like thyroxine, and tri-iodothyronine. It is crucial for regulating all the metabolic events	FAO (1987), Sutija and Joss (2006)
Fluorine (F)	Fluorine has a crucial role in the defense mechanism against fluoride intoxication because of the removal of fluoride from body circulation. In addition, fluoride accumulation can play an important role in the hardening of hard tissues mainly the exoskeleton of marine crustaceans due to the combination of fluoride with calcium and phosphorous which forms fluorapatite	Sigler and Neuhold (1972), Kessabi et al. (1984), Sands et al. (1998)
Tin (Sn) Silicon (Si) Vanadium (Va) Arsenic (As) Molybdenum (Mo)	These trace elements are essential for the normal growth, development, and biology of organisms. As they may have a physiological role that influences methionine/methyl metabolism in animals, however, there are no specific reports available in fish and crustaceans	FAO (1987), Yokoi et al. (1990), Nielsen (1990b), Nielsen (1996), Lall (2002), Jugdaohsingh (2007)

characteristics have been studied relative to the feeding at graded levels. These levels of essential minerals are over a wide range, from zero to levels far beyond optimal. This is because the requirement of each mineral is based on the type of mineral and selected species. In this line, many studies have reported the optimum dietary requirement of minerals including trace elements in fish (Table 16.2) and crustaceans (Table 16.3). In the present chapter, the role of dietary macro minerals and trace elements on survival, food index, growth, digestive enzymes activity, proximate composition, nonspecific immune response including antioxidants, and disease resistance against pathogens in fish and crustaceans is summarized and discussed.

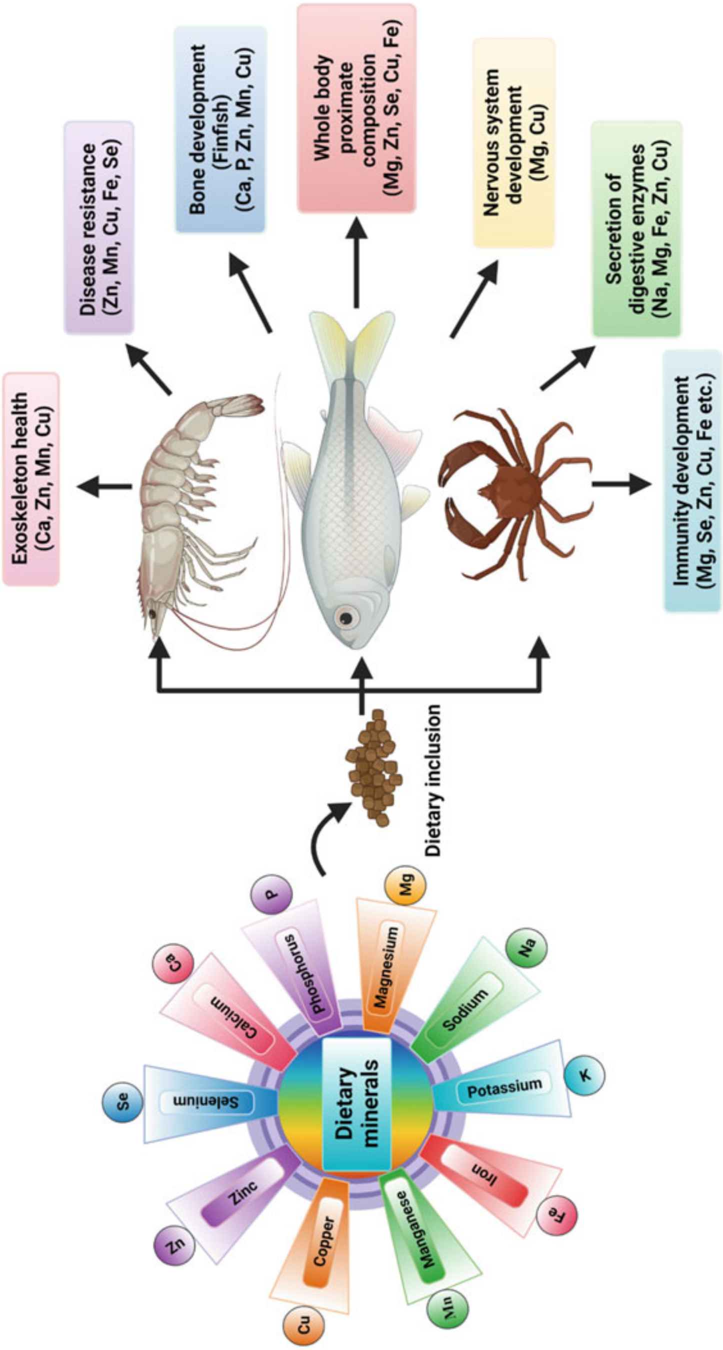

Fig. 16.1 Role of dietary minerals in fish and crustaceans

Table 16.2 Role of dietary minerals in fishes

Mineral	Species	Optimized dose	Exp. duration	Initial size of the organism	Survival, growth, proximate composition and Digestive enzymes	Immune response	References
Ca	*S. marmoratus*	2 g kg^{-1}	84 days	0.82 g	WG, FE (↑), SR (↔)	–	Hossain and Furuichi (2000)
	C. idella	16 g kg^{-1}	56 days	3.96 g	WG, FI, FE, PER (↑)	–	Liang et al. (2012)
	E. coioides	6.0 g kg^{-1}	70 days	29.8 g	WG, FI, FE, SR (↑) Protein, lipid (↔)	–	Ye et al. (2006)
	A. nobilis	12.6 g kg	56 days	105.52 g	WG, SGR, SR (↑) FCR (↓) Protein, lipid, ash (↔)	RBC, HCT (↔)	Liang et al. (2018)
	O. niloticus × *O. aureus*	10 g kg^{-1}	56 days	0.52 g	WG, SGR, FE, SR (↑)	–	Shiau and Tseng (2007)
	L. rohita	5.11 g kg^{-1}	56 days	1.94 g	WG, FI, PER (↑) FCR (↓) Protein, lipid (↑)	–	Musharraf and Khan (2020)
	I. punctatus	15 g kg^{-1}	150 days	6 g	WG (↑)	–	Andrews et al. (1973)
K	*C. idella*	9.87 g kg^{-1}	56 days	3.96 g	WG, FE, SGR, FI (↑)	–	Liang et al. (2014)
	O. niloticus × *O. aureus*	3 g kg^{-1}	56 days	0.77 g	WG, FE, PER, SR (↑)	$Na^{+}-K^{+}$ ATPase (↔)	Shiau and Hsieh (2001a)
Na	*L. rohita*	10 g kg^{-1}	120 days	1.6 g	WG, PER (↑) Protein (↔), lipid (↑) Protease (↑) Amylase (↑) Lipase (↑)	–	Keshavanath et al. (2003)
	C. mrigala	10 g kg^{-1}	120 days	1.2 g			
	C. carpio	10 g kg^{-1}	120 days	0.5 g			
	O. niloticus × *O. aureus*	0.2 g kg^{-1}	56 days	0.69 g	WG, FE, SR (↑)	–	

							Shiau and Lu (2004)
	P. fulvidraco	0.5 and 1 g kg^{-1}	56 days	1.26 g	SGR, hepatic trypsin, stomachic lipase, intestinal lipase, crude protein, ash (↑) FCR (↓)	ALP (↑)	Zhao et al. (2021)
P	*H. bidorsalis*	0.7 g kg^{-1}	56 days	3.33 g	WG, SGR, PER (↑) FCR (↓) Protein, lipid (↑)	–	Adekunle (2012)
	O. niloticus	0.75 g kg^{-1}	56 days	25.02 g	WE, SR (↑), FCR (↓) Protein (↔), lipid (↓)	ALP (↑)	Phromkunthong and Udom (2008)
	C. leather	7.1 g kg^{-1}	70 days	7.94 g	WG, SGR, PER, SR (↑) FCR (↓)	–	Yu et al. (2013)
	I. punctatus	5.2 g kg^{-1}	77 days	145–155 g	WG, FE, SR (↑)	–	Wilson et al. (1982)
	C. chanos	0.88 g kg^{-1}	112 days	2.5 g	WG, SGR, FE, SR (↑)	–	Borlongan and Satoh (2001)
	S. salar	17 g kg^{-1}	63 days	9.4 g	WG, FE (↑)	–	Åsgård and Shearer (1997)
	C. gariepinus	8 g kg^{-1}	84 days	10.2 g	WG, SGR (↑), FCR (↓) Protein (↑), ash (↔)	–	Nwanna et al. (2009)
	A. baerii	6 g kg^{-1}	56 days	14.50 g	WG, SGR (↑), FCR (↓) Protein, lipid (↔)	–	Xu et al. (2011)
	O. mykiss	10.5 g kg^{-1}	56 days	120 g	WG, FI (↑)	–	Morales et al. (2018)
	S. macrocephalus	8.9 g kg-1	56 days	11. 44 g	WG, FE, PER, SR (↑) Lipid, ash (↔)	LYZ (↑)	Shao et al. (2008)

(continued)

Table 16.2 (continued)

Mineral	Species	Optimized dose	Exp. duration	Initial size of the organism	Survival, growth, proximate composition and Digestive enzymes	Immune response	References
	C. idella	7.10 g kg^{-1}	60 days	256.22 g	WG, SGR, FE, FI (↑)	–	Chen et al. (2017)
	S. ocellatus	11.6 g kg^{-1}	77 days	1.3 g	WG, SR (↑)	–	Davis and Robinson (1987)
Mg	*I. punctatus*	0.57 mg kg^{-1}	70 days	107 g	WG, FE, SR (↑)	RBC, HCT, Hb (↑)	Gatlin et al. (1982)
	C. idella	5.92 g kg^{-1}	56 days	5.56 g	WG, FE, FI, SR (↑) Lipid (↑)	ALP (↑)	Wang et al. (2011)
	A. schrenckii♀ × *A. baerii*♂	0.5 g kg^{-1}	56 days	7.63 g	WG (↑)	SOD, CAT, GPx (↑) MDA (↓)	Zhang et al. (2021)
	S. gairdneri	0.54 mg kg^{-1}	140 days	1.5 g	WG, SR (↑)	–	Knox et al. (1981)
Fe	*I. punctatus*	30 mg kg^{-1}	70 days	7.1 g	WG, FE, SR (↑)	Hb, HCT (↑) RBC, MCV (↑)	Gatlin and Wilson (1986a)
		20 mg kg^{-1}	91 days	4.7 g	WG, FE, SR (↑)	TBC, HCT (↑)	Lim and Klesius (1997)
		0.3 g kg^{-1}	98 days	10.6 g	WG, SR (↑)	TBC, HCT, Hb (↑)	Lim et al. (2000)
		60 mg kg^{-1}	56 days	8.5 g	–	SR against (↑) *E. ictaluri*	Sealey et al. (1997)
	O. mykiss	25 mg kg^{-1}	140 days	1.5 g	WG, SR (↑)	Hb, HCT (↑) Plasma protein (↑)	Desjardins et al. (1987)
	O. niloticus × *O. aureus*	1.5 g kg^{-1}	56 days	0.63 g	WG, FE, SR (↑)	RBC, Hb (↑) MCV, MCH, HCT (↑)	Shiau and Su (2003)
	O. niloticus	14. 58 g kg^{-1}	84 days	3.75 g	WG, SGR, PER (↑) FCR (↓)	RBC, Hb, HCT (↑)	El-Saidy and Gaber (2004)
	C. carpio	147.4 mg kg^{-1}	60 days	11.4 g		ALP (↑)	

					WG, FE (↑) Protein (↑) Lipid, ash (↔) Trypsin, lipase, α-amylase (↑)		Ling et al. (2010)
	C. gariepinus	30 g kg^{-1}	96 days	112 g	WG, SGR, SR (↑) FCR (↓) Protein, lipid, ash (↔)	HCT, Hb, RBC, WBC, MCH, MCV (↔)	Siqwepu et al. (2020)
Zn	*C. auratus*	60 mg kg^{-1}	63 days	0.51 g	WG, FCE, SR (↑)	SOD, ALP (↑)	Hasnat et al. (2012)
	I. punctatus	60 mg kg^{-1}	56 days	78 g	WG, FE, SR (↑)	–	Gatlin III and Wilson (1983)
	L. rohita	20 mg kg^{-1}	45 days	5.06 g	WG, SGR (↑), Protease, lipase, amylase (↑)	SGOT, SGPT, PO, PHA, RB, SOD (↑)	Mondal et al. (2020)
		42 mg kg^{-1}	90 days	3.15 g	WG, FI, SGR, SR (↑) Protein, lipid (↔)	–	Akram et al. (2019)
		10 mg kg^{-1}	120 days	368 g	WG, (↑), FCR (↔)	RB, SOD, LYZ, SR (↑) against *A. hydrophila*	Swain et al. (2019)
	S. rivulatus	30 mg kg^{-1}	56 days	0.20 g	WG, PER, SR (↑),FCR (↓)	SOD, CAT, GPx, LYZ, PO (↑) MDA (↓)	Sallam et al. (2020)
	H. huso	15, 30, and 60 mg kg^{-1}	84 days	8.4 g	FW, WG, SGR (↑)	GST (↑) SGOT, SGPT (↓)	Mohseni et al. (2021)
Cu	*E. malabaricus*	6.56 mg kg^{-1}	56 days	13.35 g	WG, FE, SR (↑)	Cu-Zn SOD (↑) MDA (↓)	Lin et al. (2008)
	Salmo salar	5 mg kg^{-1}	84 days	7.5 g	WG (↑)	–	

(continued)

Table 16.2 (continued)

Mineral	Species	Optimized dose	Exp. duration	Initial size of the organism	Survival, growth, proximate composition and Digestive enzymes	Immune response	References
							Lorentzen et al. (1998)
	I. punctatus	8 mg kg^{-}	91 days	83 g	SR (↑)	SOD, cu-SOD, Mn-SOD (↔)	Gatlin and Wilson (1986b)
		80 mg kg^{-}	28 days	6.7 g	Growth (↔)	SR (↑) against *F. columnare*	Farmer et al. (2017)
	M. amblycephala	3 mg kg^{-1}	56 days	30.8 g	EG, SGR, SR (↑) FCR (↓)	Cu- Zn-SOD, CAT, GSH-Px (↔)	Shao et al. (2012)
	S. zarudnyi	3 mg kg^{-1}	84 days	23.97 g	SGR, SR (↑)	RBC, HCT, Hb, serum protein, SOD, CAT, GPx, LYZ (↑), MDA (↓)	Afshari et al. (2021)
Se	*M. salmoide*	0.6–1 mg kg^{-1}	56 days	4.95 g	WG, PER (↑), FCR (↓) Protein, lipid (↔)	GPx (↑), MDA (↔)	Zhu et al. (2012)
	S. gairdneri	41.1 mg kg^{-1}	140 days	4 g	WG, FI, SR (↑)	HCT, RBC, GPx (↑) against *E. ictaluri*	Hilton et al. (1980)
	A. regius	3.98 mg kg^{-1}	63 days	3.2 g	WG, SR (↑),FCR (↓)	SOD, CAT (↑) SGOT, SGPT (↑)	Khalil et al. (2019)
	E. malabaricus	0.5 mg kg^{-1}	56 days	12.20 g	WG, FE, SR (↑)	GPx, GSH (↑)	Lin and Shiau (2005)
	I. punctatus	1–5 mg kg^{-1}	98 days	70–72 g	WG, SR (↑) Protein, lipid, ash (↑)	Se-GSH, non se-GSH (↑)	Gatlin and Wilson (1984)
	S. aurata	0.2 mg kg^{-1}	636 days	6.2 g	WG, FI, SR (↑) Protein, lipid (↔)	–	Mechlaoui et al. (2019)
	R. canadum	1 mg kg^{-1}	70 days	6.27 g	SGR, PE, SR (↑)	Se- GPx (↑)	

							Liu et al. (2010a)
	C. carpio	1.2 mg kg^{-1}	56 days	125.26 g	WG (↑) FCR (↓)	Serum protein (↑) MDA (↓)	Luo et al. (2021)
	L. rohita	0.3 mg kg^{-1}	120 days			RB, SOD, LYZ, SR (↑) against *A. hydrophila*	Swain et al. (2019)
	O. niloticus	0.7 mg kg^{-1}	70 days	33 g	WG, SGR (↑)	RBC, Hb, HCT, LYZ (↑) against *S. iniae*	Neamat-Allah et al. (2019)
Cr	*C. carpio*	0.5 mg kg^{-1}	56 days	4.95 g	WG, PER, SGR (↑) FCR (↓) Protein, lipid (↑)	–	Ahmed et al. (2012a, b)
	O. mykiss	4 mg kg^{-1}	58 days	225 g	–	Blood glucose and fat	Küçükbay et al. (2006)
	C. idella	0.8 mg kg^{-1}	70 days	13.60 g	WG, FER, PER (↑) Protein, lipid ash (↔)	–	Liu et al. (2010b)
	L. rohita	0.3 mg kg^{-1}	90 days	1.81 g	WG, SGR (↑)	–	Asad et al. (2019)
	O. niloticus	0.4 mg kg^{-1}	58 days	225 g	–	Blood glucose and fat	Mehrim (2012)
F	*A. baerii*	75.2 mg kg^{-1}	84 days	11.99 g	WG, SGR (↑)	–	Shi et al. (2013)
	S. quinqueradiata	160 mg kg^{-1}	95 days	57.3 g	WG, SGR, FI, FE (↑) SR (↔) Protein, lipid (↔)	–	Yoshitomi and Nagano (2012)

ALP alkaline phosphatase, *CAT* catalase, *FCR* feed conversion ratio, *FE* feeding efficiency, *FI* feed intake, *GPx* glutathione peroxidase; *GSH* glutathione, *GSH-Px* plasma glutathione peroxidase, *GST* glutathione S-transferase, *Hb* hemoglobin, *HCT* hematocrit, *LYZ* lysozyme, *MCH* mean corpuscular hemoglobin, *MCV* mean corpuscular volume, *MDA* malondialdehyde, Na^{+}/K^{+}ATPase– Sodium–potassium adenosine triphosphatase, *PAH* phagocytic activity, *PER* protein efficiency ratio, *PO* phenoloxidase, *RB* respiratory burst, *RBC* red blood cells, *SGOT* serum glutamic oxaloacetic transaminase, *SGPT* serum glutamic pyruvic transaminase, *SOD* superoxide dismutase; *SR* survival, *TBC* total blood cells, *WBC* white blood cells, *WG* weight gain, *Ca* calcium, *K* potassium, *Na* sodium, *P* phosphorus, *Mg* magnesium, *Fe* iron, *Zn* zinc, *Cu* copper, *Se* selenium, *Cr* chromium, *Fe* fluoride, (↑) significant increase compared to control, (↓) significant decrease compared to control, (↔) insignificant alteration compared to control.

Table 16.3 Role of dietary minerals in crustaceans

Mineral	Organisms	Optimized dose	Exp. duration	Initial size of the organism	Survival, growth, proximate composition & digestive enzymes	Immune response	References
Ca	*P. indicus*	13 mg kg^{-1}	45 days	0.15 g	WG (↑), FCR (↓), SR (↔)	–	Ali (1999)
	P. vannamei	20 mg kg^{-1}	33 days	0.027 g	SR (↑)	–	Davis et al. (1993a, b)
K	*L. vannamei*	5–25 g kg^{-1}	46 days 56 days	0.5 g 0.8 g	WG, SGR, PER, SR (↑)	–	Zhu et al. (2006), Roy et al. (2007b)
	P. monodon	15 g kg^{-1}	56 days	0.75 g	WG, FE, PER, SR (↑)	–	Shiau and Hsieh (2001b)
Na	*M. rosenbergii*	20 g kg^{-1}	120 days	1.11 g	WG, PER, SR (↑), FCR (↓) Protein, lipid (↔) Protease, amylase, lipase (↑)	–	Keshavanath et al. (2003)
	L. vannamei	10 g kg^{-1}	49 days	0.5 g	WG, SR (↔)	–	Cheng et al. (2005b)
P	*P. monodon*	15 g kg^{-1}	45 days	2.54 g	WG, SR (↑), protein (↑)	–	Ambasankar et al. (2006)
	P. vannamei	20 mg kg^{-1}	33 days	0.027 g	SR (↑)	–	Davis et al. (1993a, b)
	E. sinensis	9.9 g kg^{-1}	56 days	0.38 g	WG, FI, SGR, SR (↑) Protein, lipid, ash (↔)	–	Lei et al. (2021)
Mg	*L. vannamei*	3.2 g kg^{-1}	49 days	0.5 g	WG (↑), SR (↓), protein (↑)	Na^+ / K^+ ATPase (↓) under salinity stress	Cheng et al. (2005a); Roy et al. 2007a, b)
	M. rosenbergii	0.5 g kg^{-1}	90 days	0.11 g	WG, SGR, SR (↑) Protein, lipid carbohydrate (↑) Protease, amylase, lipase (↑)	SOD, CAT, LPO, GOT, GPT (↔)	Srinivasan et al. (2017)
Fe	*P. vannamei*	20 mg kg^{-1}	28 days	26–32 mg	WG, SR (↑)	–	Davis et al. (1992)
	M. rosenbergii	10–20 mg kg^{-1}	90 days	0.11 g	WG, SR, FI, SGR (↑) Protein, lipid, carbohydrate, EAA, FA (↑) Protease, amylase, lipase (↑)	SOD, CAT, LPO, GOT, GPT (↔) THC, DHC (↑)	Srinivasan et al. (2016)
	E. sinensis	177 mg kg^{-1}	56 days	0.83 g			Song et al. (2021)

					WG, SGR, SR (↑) Protein, lipid (↔)	SOD, CAT, GSH (↑)	
Zn	*P. monodon*	40 $mg\ kg^{-1}$	56 days	0.44 g	WG, SR (↑)	SOD, CAT, LPO (↔) THC, DHC (↑)	Shiau and Jiang (2006)
	P. vannamei	15 $mg\ kg^{-1}$	33 days	0.058 g	WG, SR (↑)	–	Davis et al. (1993a)
	P. vannamei	65.5 $mg\ kg^{-1}$	56 days	1.34 g	WG, FI, SGR, SR (↑)	ProPO (↑)	Shi et al. (2021)
	M. rosenbergii	60 $mg\ kg^{-1}$	90 days	0.19 g	WG, SR, FI, SGR (↑) Protein, lipid, carbohydrate, EAA, FA(↑) Protease, amylase, lipase (↑)	SOD, CAT, LPO, GOT, GPT (↔) THC, DHC (↑)	Muralisankar et al. (2015), Thirunavukkarasu et al. (2019)
	E. sinensis	20 $mg\ kg^{-1}$	56 days	49.68 mg	WG, SR (↑)	–	Li et al. (2010)
Cu	*L. vannamei*	32 $mg\ kg^{-1}$	42 days	0.057 g	WG (↑)	–	Davis et al. (1993a)
	P. monodon	20 $mg\ kg^{-1}$	56 days	0.29 g	WG, FE, PER, SR (↑) MUFA, PUFA (↑)	–	Lee and Shiau (2002)
	L. vannamei	39.70 $mg\ kg^{-1}$	56 days	1.86 g	WG, FE, PER, SGR, SR (↑) Protein, lipid (↔)	–	Yuan et al. (2019)
	M. rosenbergii	40 $mg\ kg^{-1}$	90 days	0.18 g	WG, SR, FI, SGR (↑) Protein, lipid, carbohydrate (↑) Protease, amylase, lipase (↑)	SOD, CAT, LPO, GOT, GPT (↔)	Muralisankar et al. (2016)
	P. indicus	10 $mg\ kg^{-1}$	75 days	70 mg	WG, SR (↑)	–	Ali (2000)
	E. sinensis	40 $mg\ kg^{-1}$	56 days	0.45 g	WG (↑)	PO, THC (↑) SR (↑) against *A. hydrophila*	Sun et al. (2013)
Se	*M. rosenbergii*	0.5–1 $mg\ kg^{-1}$	75 days	NS	–	GPx, GST (↑) THC, PO, RB, PHA	Chiu et al. (2010)

(continued)

Table 16.3 (continued)

Mineral	Organisms	Optimized dose	Exp. duration	Initial size of the organism	Survival, growth, proximate composition & digestive enzymes	Immune response	References
						(↑) against *D. hansenii*	
	M. nipponense	0.47 mg kg^{-1}	56 days	0.133 g	WG, SR (↑)	SOD (↑)	Kong et al. (2017)
	P. chinensis	20 mg kg^{-1}	28 days	5–6.5 cm	WG, SR (↑)	–	Yuchuan and Fayi (1993)
	P. vannamei	0.3 mg kg^{-1}	35 days	1–2 g	WG (↑)	GH (↑) SR (↑) against TSV	Sritunyalucksana et al. (2011)
	C. cainii	0.2 g kg^{-1}	90 days	3.29 g	WG, SGR, SR (↑)	THC, DHC (↑) THC (↑) against *V. mimicus*	Nugroho and Fotedar (2013)

ALP alkaline phosphatase, *CAT* catalase, *DHC* differential hemocyte counts, *FCR* feed conversion ratio, *FE* feeding efficiency, *FI* feed intake, *GH* granular hemocytes, *GOT* glutamic oxaloacetic transaminase, *GPT* glutamic pyruvic transaminase, *GPx* glutathione peroxidase, *GSH* glutathione, *GST* glutathione S-transferase, *LPO* lipid peroxidation, *MDA* malondialdehyde, Na^+/K^+ATPase–sodium–potassium adenosine triphosphatase, *PER* protein efficiency ratio, *PO* phenoloxidase, *ProPO* prophenoloxidase, *RB* respiratory burst activity, *SOD* superoxide dismutase, *SR* survival, *THC* total hemocyte counts, *TSV* Taura syndrome virus, *WG* weight gain, *Ca* calcium, *K* potassium, *Na* sodium, *P* phosphorus, *Mg* magnesium, *Fe* iron, *Zn* zinc, *Cu* copper, *Se* selenium, *Cr* chromium, *Fe* fluoride, (↑) significant increase compared to control, (↓) significant decrease compared to control, (↔) insignificant alteration compared to control.

16.2 Effects of Dietary Minerals on Food Index, Survival, and Growth

Feed index, survival, and growth are major factors affecting the economy of the cultivable fish and crustaceans. In the aquaculture industry, feed is one of the primary factors which affect survival and growth. Minerals are part of an essential nutrient in aquafeeds. Minerals act as catalysts for many biological reactions within the body, including muscle response, hormones, digestion, transmitting senses through the nervous system, and utilization of nutrients from diets. The optimal level of each mineral is required for better feed intake and growth of aquatic animals. The optimal level of minerals are necessary for maintain normal physiological function of aquatic animals which leads to better growth and survival. The macromineral calcium (calcium lactate, calcium chloride, calcium carbonate, and calcium phosphate) incorporated feed fed fish, *Sebastiscus marmoratus, Ctenopharyngodon idella, Epinephelus coioides, Oreochromis niloticus* × *Oreochromis aureus, Labeo rohita, Ictalurus punctatus* and the shrimps, *Penaeus indicus*, and *Penaeus vannamei* had shown significant improvements in survival, weight gain, feed intake, feeding efficiency and protein efficiency ratio (Andrews et al. 1973; Davis et al. 1993b; Ali 1999; Hossain and Furuichi 2000; Ye et al. 2006; Shiau and Tseng 2007; Liang et al. 2012; Kalantarian et al. 2013; Musharraf and Khan 2020). Shiau and Hsieh (2001a, b), Zhu et al. (2006), Roy et al. (2007a, b), and Liang et al. (2014) reported that the dietary addition of potassium had produced better survival and significant improvements in weight gain, feeding efficiency, specific growth rate, and protein efficiency ratio in the white shrimp, *L. vannamei*, black tiger shrimp, *P. monodon,* and the fish grass carp, *C. idella*. Similarly, the fish *L. rohita*, *Cyprinus carpio, Cirrhinus mrigala,* and *O. aureus* × *O. niloticus* and the crustaceans *M. rosenbergii* and *L. vannamei* showed significant elevations in survival, growth (weight gain and specific growth rate), and feeding efficiency after fed to sodium incorporated diet (Keshavanath et al. 2003; Shiau and Lu 2004; Cheng et al. 2005a; Zhao et al. 2021). Further, dietary addition of phosphorus significantly promoted the survival, weight gain, specific growth rate, feed intake, and feeding efficiency in the fish *Heterobranchus bidorsalis*, *O. niloticus, Pelteobagrus fulvidraco, Clarias leather, I. punctatus, Chanos chanos, S. salar, Clarias gariepinus, Acipenser baerii, Sciaenops ocellatus, O. mykiss, C. idella, Sparus macrocephalus* and crustaceans *P. monodon, L. vannamei,* and *Eriocheir sinensis* (Davis and Robinson 1987; Davis et al. 1993b; Åsgård and Shearer 1997; Borlongan and Satoh 2001; Ambasankar et al. 2006; Phromkunthong and Udom 2008; Shao et al. 2008; Nwanna et al. 2009; Xu et al. 2011; Adekunle 2012; Yu et al. 2013; Chen et al. 2017; Morales et al. 2018; Lei et al. 2021). Moreover, it has also been observed earlier that the dietary inclusions of magnesium greatly promoted the survival of *O. mykiss*, *I. punctatus, C. idella, Salmo gairdneri, Acipenser schrenckii* × *A. baerii, M. rosenbergii*, and *L. vannamei* (Knox et al. 1981; Gatlin et al. 1982; Cheng et al. 2005a, b; Roy et al. 2007a, b; Wang et al. 2011; Srinivasan et al. 2017; Zhang et al.

2021). These reports indicate the influence of dietary macro minerals on the survival, feed intake, and growth of fish and crustaceans.

Trace elements also play a pivotal role in maintaining normal physiological functions which led to the survival of aquatic animals. The studies on various fish species, such as *I. punctatus*, *O. mykiss*, *O. niloticus*, *O. niloticus* × *O. aureus, C. gariepinus,* and *C. carpio*, and crustaceans, *P. vannamei* and *M. rosenbergii,* indicated significant improvements in survival, growth, and feeding efficiency after fed to dietary supplementation of iron (Fe_2O_3, $FeSO_4$, and $FeC_6H_6O_7$) (Gatlin and Wilson 1986a; Desjardins et al. 1987; Davis et al. 1992; Lim and Klesius 1997; Lim et al. 2000; Shiau and Su 2003; El-Saidy and Gaber 2004; Ling et al. 2010; Srinivasan et al. 2016; Siqwepu et al. 2020). The maximum level of feed intake, feeding efficiency, followed by increased survival, weight gain, and specific growth rate have been noticed in fishes like *O. niloticus*, *Carassius auratus*, *Siganus rivulatus, Huso huso*, *L. rohita,* and *I. punctatus* and crustaceans like *P. monodon, P. vannamei, M. rosenbergii,* and *E. sinensis* fed to graded level of zinc supplemented diets (Gatlin and Wilson 1986b; Shiau and Jiang 2006; Li et al. 2010; Hasnat et al. 2012; Muralisankar et al. 2015; Akram et al. 2019; Thirunavukkarasu et al. 2019; Mondal et al. 2020; Sallam et al. 2020; Mohseni et al. 2021; Shi et al. 2021). Also, the dietary copper ($CuSO_4$ and $CuCl_2$) supplemented feed fed fishes (*Epinephelus malabaricus*, *Schizothorax zarudnyi*, *Salmo salar*, *I. punctatus, Megalobrama amblycephala*) and crustaceans (*M. rosenbergii*, *P. indicus, L. vannamei,* and *P. monodon*) attained maximum feed intake, survival, and growth (final weight, weight gain, and specific growth rate) have been reported previously (Gatlin III and Wilson 1986; Lorentzen et al. 1998; Ali 2000; Lee and Shiau 2002; Lin et al. 2008; Shao et al. 2012; Muralisankar et al. 2016; Yuan et al. 2019; Afshari et al. 2021). Further, the dietary incorporation of selenium showed a higher survival rate, increased feed intake, weight gain, feeding efficiency, and specific growth rate in fishes such as *Micropterus salmoide*, *S. gairdneri*, *Argyrosomus regius, Sparus aurata, E. malabaricus*, *I. punctatus, C. carpio,* and *Rachycentron canadum* and crustaceans such as *P. vannamei, Macrobrachium nipponense,* and *Penaeus chinensis* (Hilton et al. 1980; Gatlin and Wilson 1984; Yuchuan and Fayi 1993; Lin and Shiau 2005; Liu et al. 2010a; Sritunyalucksana et al. 2011; Zhu et al. 2012; Chen et al. 2013; Kong et al. 2017; Khalil et al. 2019; Mechlaoui et al. 2019; Luo et al. 2021). Furthermore, the fishes like *Cyprinus carpio*, *O. mykiss*, *C. idella,* and *L. rohita* showed better survival, protein efficiency ratio, feeding efficiency, and growth (weight gain and specific growth rate) when fed on chromium supplemented diets (Küçükbay et al. 2006; Liu et al. 2010b; Ahmed et al. 2012a, b; Asad et al. 2019). It is reported that the manganese enriched *Artemia* diets gently promoted the survival of sea bream, *Pagrus major*. A significant increment in feed intake, feeding efficiency, total weight gain, and specific growth rate has been recorded in the fishes *A. baerii* and *Seriola quinqueradiata* fed to dietary fluoride (Yoshitomi and Nagano 2012; Shi et al. 2013). Therefore, above mentioned studies clearly indicate that minerals including trace elements have a significant role in the maintenance of physiological functions in fish and crustaceans, it leads to reduced stress and increased feed intake, growth, and survival.

16.3 Influence of Dietary Minerals on Digestive Enzymes

Activities of digestive enzymes in the fish and crustaceans play a central role in nutritional physiology and may directly or indirectly regulate survival and growth (Lovett and Felder 1990). The fish and crustaceans have digestive enzymes such as proteolytic enzymes (trypsin and carboxypeptidase), carbohydrate enzymes (maltase and amylase), and lipolytic enzymes (lipase) which are essential for the hydrolysis of proteins, carbohydrates, and lipids, respectively (Bone and Moore 2008). Animals rely on a functional digestive system to efficiently utilize the nutrients present in the food and the capability to hydrolyze, absorb, and assimilate the nutrients (Fernández-Reiriz et al. 2001). In another hand, the quality and nutritive value of formulated feeds depend on the digestibility of the individual components (D'Abramo and Sheen 1994; del Carmen González-Peña et al. 2002). Dietary supplementation of minerals can influences the digestive enzyme activities of fish and crustaceans. Dietary additions of sodium showed significant elevations in the intestinal and hepatopancreatic enzymes such as protease, amylase, and lipase in the fish (*L. rohita, C. mrigala, C. carpio,* and *P. fulvidraco*) and prawn (*M. rosenbergii*) (Keshavanath et al. 2003; Zhao et al. 2021). Srinivasan et al. (2017) recorded substantial elevations in the activity of digestive enzymes protease, lipase, and amylase of *M. rosenbergii* fed to dietary magnesium. Also, it has been noticed that the trace element iron included feed fed fish *C. carpio* and prawn *M. rosenbergii* had produced an elevated level of trypsin, lipase, and amylase (Ling et al. 2010; Srinivasan et al. 2016). Also, the fish *L. rohita* and the prawn *M. rosenbergii* had shown significant improvement in intestinal digestive enzymes activity (protease, lipase, and amylase) fed on dietary zinc (Muralisankar et al. 2015; Mondal et al. 2020) and copper (Muralisankar et al. 2016). The previous studies indicate the ability of different dietary minerals on the activity of the digestive enzymes. Nevertheless, the studies are scanty on the effects of minerals on the digestive enzymes of different species, hence, more studies are required to clarify the impact of minerals on different fish and crustaceans.

16.4 Effects of Dietary Minerals on Proximate Composition

The quality of the flesh is determined by analyzing the proximate composition (crude protein, lipid, nitrogen free extract, fiber, ash, and moisture) of the whole body and or muscle of any edible species. In aquatic edible species, the proximate composition is one of the most crucial factors to evaluate the nutrient quality of animals. Different levels of dietary minerals showed a correlation with the proximate composition of fish and crustaceans (Muralisankar et al. 2015, 2016; Musharraf and Khan 2020). The macromineral, calcium enriched feed fed edible fish *L. rohita* produced significant improvements in whole body crude protein and crude lipid (Musharraf and Khan 2020). In this context, the fishes such as *E. coioides* and *A. nobilis* fed to different levels of calcium enriched diets showed insignificant alterations in crude protein, lipid, and ash (Ye et al. 2006; Liang et al. 2018). Similarly, Keshavanath et al. (2003) reported from their findings, sodium enriched feed fed fish *L. rohita*, *C. carpio,* and *C. mrigala* showed significant elevation on muscle lipid content and an insignificant alteration in protein level. Also, the same study reported that there was no significant variation in the level of muscle protein and lipid in the freshwater prawn *M. rosenbergii*. Further, the *P. fulvidraco* fed to dietary sodium had produced significant elevations in muscle protein and ash contents (Zhao et al. 2021). The fishes like *H. bidorsalis* and *C. gariepinus* fed to the macromineral phosphorus incorporated feed have shown significant elevation in crude protein and lipid (Nwanna et al. 2009; Adekunle 2012). Whereas, Phromkunthong and Udom (2008), Shao et al. (2008), and Xu et al. (2011) reported insignificant alterations in protein, lipid, and ash content in the fish *O. niloticus, S. macrocephalus,* and *A. baerii* fed on dietary addition of phosphorus. In crustaceans, the shrimp *P. monodon* fed to dietary phosphorus gained maximum level of protein in the whole carcass contents (Ambasankar et al. 2006). While, insignificant alterations in protein, lipid, and ash have been noticed in the crab *E. sinensis* fed to dietary phosphorus (Lei et al. 2021). Further, Wang et al. (2011) noticed that dietary administration of magnesium had produced significant improvement in muscle lipid content of *C. idella* (Wang et al. 2011). While, the shrimp *L. vannamei* and the prawn *M. rosenbergii* fed to dietary magnesium showed significant elevations in muscle protein, amino acids, fatty acids, lipid, carbohydrate, and total ash (Cheng et al. 2005a; Roy et al. 2007a, b; Srinivasan et al. 2017).

The effect of trace elements on the proximate composition (protein, lipid, and ash) of fish and crustaceans has also been studied by various researchers. An increase in the crude protein in *C. carpio* fed with iron included diets has been reported by Ling et al. (2010), however, the same study indicated insignificant alterations in the crude lipid and ash contents. An insignificant alteration in muscle protein, lipid, and ash levels has been recorded in the fish *C. gariepinus* fed to different levels of iron (Siqwepu et al. 2020). Moreover, the freshwater prawn *M. rosenbergii* had gained better protein, lipid, carbohydrate, and ash content when fed to dietary iron (Srinivasan et al. 2016). In this context, insignificant elevations in whole body protein and lipid contents in *E. sinensis* fed to dietary iron have been noticed by Song et al. (2021). Similarly, the dietary administration of zinc did not produce significant alterations in the protein and lipid levels of *L. rohita* (Akram et al. 2019). While, different concentrations of dietary zinc and copper showed significant improvements in muscle protein, lipid, carbohydrate, essential amino acids, fatty acids, and ash contents in the prawn *M. rosenbergii* (Muralisankar et al. 2015, 2016; Muralisankar et al. 2019) and the shrimps *P. monodon* and *L. vannamei* (Lee and Shiau 2002; Yuan et al. 2019). In addition to this, 1:2 ratio of manganese and zinc complex supplemented enriched *Artemia* nauplii fed sea bream, *P. major* had significant elevation in carcass protein, lipid, fatty acid, and ash content (Nguyen et al. 2008). Dietary inclusion of selenium showed considerable improvements in proximate composition (whole body protein, lipid, and ash) of *I. punctatus* (Gatlin et al. 1982). Therefore, the above-cited studies showed that minerals can affect the proximate composition of fish and crustaceans. However, some studies reported reduction and insignificant alterations in proximate composition of aquatic animals, hence, more research has to be conducted to know the effect of each mineral on different stages of fish and crustaceans.

16.5 Role of Dietary Minerals on the Immune Response

The health status of an organism can be determined by immunological parameters like hematological measurements and antioxidants enzymes. In aquatic organisms, the immunity has been determined by total blood cells count (TBC), red blood cells count (RBC), phagocytosis activity (PHA), hemoglobin (Hb), hematocrit (HCT), etc., and antioxidant parameters such as superoxide dismutase (SOD), catalase (CAT), lipid peroxidation (LPO), glutamic oxaloacetic transaminase (GOT), glutamate pyruvate transaminase (GPT), glutathione peroxidase (GPx), etc. The effect of dietary minerals like potassium, sodium, magnesium, iron, zinc, selenium, copper, etc., on immune responses of fish and crustaceans has been proved by several researchers (Gatlin et al. 1982; Lim and Klesius 1997; Shiau and Hsieh 2001a; Cheng et al. 2005a; Muralisankar et al. 2015, 2016; Srinivasan et al. 2016; Khalil et al. 2019; Mondal et al. 2020; Afshari et al. 2021; Zhao et al. 2021). The increased alkaline phosphatase (ALP) and Lysozyme (LYZ) activities in the fish *P. fulvidraco, O. niloticus,* and *S. macrocephalus* fed to diets containing sodium and potassium have been observed earlier (Phromkunthong and Udom 2008; Shao et al. 2008; Zhao et al. 2021). Magnesium included diet fed fishes (*I. punctatus, C. idella,* and *A. schrenckii* × *A. baerii*) produced significant elevations in hematological parameters (RBC, HCT, Hb, and ALP) and antioxidant enzymes (SOD, CAT, and GPx); however, the hybrid fish *A. schrenckii* × *A. baerii* showed a significant decrease in the production of Malondialdehyde (MDA) (Gatlin et al. 1982; Wang et al. 2011; Zhang et al. 2021). In this context, some macro minerals like calcium and potassium did not produce any significant alterations in RBC, HCT, and Na^+ / K^+ ATPase levels in *A. nobilis* and *A. schrenckii* × *A. baerii* (Shiau and Hsieh 2001b; Liang et al. 2018). Moreover, Srinivasan et al. (2016) observed that the freshwater prawn *M. rosenbergii* showed insignificant alterations in the activity of antioxidant enzymes (SOD and CAT), LPO, and metabolic enzymes (GOT and GPT) fed to 0.5 g kg^{-1} of dietary iron, whereas prawn fed to beyond 0.5 g kg^{-1} of dietary iron showed significant alterations in these activities.

The dietary trace minerals are also playing a major role in the immune system of fish and crustaceans. The significant increments in TBC, RBC, HCT, mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), ALP, and total plasma protein levels in the fishes such as *I. punctatus, O. mykiss, O. niloticus* × *O. aureus,* *O. niloticus, C. carpio*, and *C. gariepinus* fed on dietary iron have been reported in earlier studies (Gatlin and Wilson 1986a; Desjardins et al. 1987; Lim and Klesius 1997; Lim et al. 2000; Shiau and Su 2003; El-Saidy and Gaber 2004; Ling et al. 2010). Further, the dietary inclusion of iron improved the THC and DHC in the prawn *M. rosenbergii* (Srinivasan et al. 2016), and SOD, CAT, and glutathione (GSH) activities in the crab *E. sinensis* (Song et al. 2021). Administration of zinc in the diets of *C. auratus, L. rohita, S. rivulatus,* and *H. huso* attained significant improvement in phenoloxidase (PO), respiratory burst (RB), PHA, glutathione S-transferase, (GST), SOD, CAT, GPx, LYZ, ALP, serum GOT, and GPT activities (Hasnat et al. 2012; Mondal et al. 2020; Sallam et al. 2020; Mohseni et al. 2021). Moreover, the crustaceans (*P. monodon, P. vannamei*, and *M. rosenbergii*) had shown significant elevations in THC, DHC, and prophenoloxidase (ProPO) and an insignificant alteration in SOD, CAT, GOT, and GPT activities when fed after dietary zinc (Shiau and Jiang 2006; Muralisankar et al. 2015; Shi et al. 2021). The dietary inclusion of copper on the fishes (*E. malabaricus* and *S. zarudnyi*) showed significant improvements in RBC, HCT, Hb, Cu-Zn SOD, SOD, GPx, LYZ, and serum protein levels (Lin et al. 2008; Afshari et al. 2021). However, some fishes like *M. amblycephala* and *I. punctatus* and the prawn *M. rosenbergii* showed insignificant alterations in SOD, Cu-SOD, Mn- SOD, CAT GSH, and GPx activities fed after copper included diets has also been reported (Gatlin and Wilson 1986b; Shao et al. 2012; Muralisankar et al. 2016) which indicates the effects of dietary copper level on different species. Moreover, the significant elevations in antioxidants, such as SOD, CAT, GSH, Se-GSH, GPx, and serum protein levels were recorded in different fish species including *M. salmoide, A. regius, E. malabaricus, I. punctatus, R. canadum,* and *C. carpio* fed to dietary selenium (Gatlin and Wilson 1984; Lin and Shiau 2005; Liu et al. 2010a; Zhu et al. 2012; Khalil et al. 2019; Luo et al. 2021). In crustaceans, the freshwater prawn (*M. nipponense*) fed on dietary selenium showed significant improvement in SOD (Kong et al. 2017). Few studies have been reported that the dietary inclusion of chromium also improved the blood glucose and fat levels in the fish *O. mykiss* and *O. niloticus* (Küçükbay et al. 2006; Mehrim 2012). The above studies have indicated the effects of minerals on the immune system of fish and crustaceans. However, some studies reported that some minerals did not produce significant alteration in the immune parameters in some species of fish and crustaceans, hence, more studies are required to understand the immune stimulating mechanism of each mineral in fish and crustaceans at different life stages.

16.6 Influence of Dietary Minerals on Disease Resistance

The diseases caused by pathogens are considered as one of the major threats in aquaculture organisms. Aquatic animals including fish and crustaceans are mostly affected by pathogenic bacteria and viruses which leads to reduced immunity, followed by poor survival and growth. In culture systems, antibiotics are used in the diet of fish and crustaceans to mitigate the pathogen-mediated diseases.

However, the use of antibiotics may lead to the resistance of pathogens, suppressing the immune system of cultivable species, and also cause environmental pollution (Allameh et al. 2016). Hence, researchers are focusing to find the alternative for antibiotics to overcome the pathogen-related problems and enhance the immune system of aquatic animals. The optimal level of certain minerals, mainly the trace elements like zinc, copper, selenium, etc., can promote the survival, growth, immune system, and disease resistance against the various pathogen in fish and crustaceans (Hilton et al. 1980; Sun et al. 2013; Farmer et al. 2017; Swain et al. 2019). The fish *I. punctatus* fed to dietary iron (60 mg kg^{-1}) and copper (80 mg kg^{-1}) showed better survival against the pathogenic bacterium *Edwardsiella ictaluri* and *Flavobacterium columnare,* respectively (Sealey et al. 1997; Farmer et al. 2017). Dietary administration of zinc (10 mg kg^{-1}) produced significant elevations in RB, SOD, and LYZ activities and an increased survival rate against the pathogen *Aeromonas hydrophila* has been observed (Swain et al. 2019). Also, the fish *S. gairdneri* fed to dietary selenium (41.1 mg kg^{-1}), *L. rohita* (0.3 mg kg^{-1}), and *O. niloticus* (0.7 mg kg^{-1}) showed significant improvements in the hematological elements (RBC, HCT, and Hb), antioxidants (SOD and GPx), LYZ, and RB levels after challenged to *E. ictaluri* (Hilton et al. 1980), *A. hydrophila* (Swain et al. 2019), and *Streptococcus iniae* (Neamat-Allah et al. 2019). In crustaceans, the increased level of THC, PO, RB, PHA, and survival has been observed in the crab *E. sinensis* and prawn *M. rosenbergii* fed to dietary copper (40 mg kg^{-1}) and selenium (0.5–1 mg kg^{-1}) after challenged against the pathogens *A. hydrophila* and *Debaryomyces hansenii,* respectively (Chiu et al. 2010; Sun et al. 2013). Further, the dietary organic selenium fed smooth marron, *Cherax cainii* exhibited a significant increase in the production of THC challenged against *Vibrio mimicus* (Nugroho and Fotedar 2013). Moreover, the shrimp *P. vannamei* had shown improvements in granular hemocytes and survival against Taura syndrome virus after fed to 0.3 mg kg^{-1} of dietary selenium (Sritunyalucksana et al. 2011). The above studies showed the immune response of fish and crustaceans against pathogens.

16.7 Conclusion

The present chapter demonstrates that the optimum dietary supplementation of minerals can promote feed intake, feed efficiency, digestive enzymes secretion which leads to hydrolysis and utilization of nutrients from the diet by fish and crustaceans followed by better growth and muscle meat quality in terms of proximate composition. Also, minerals have potent to promote the nonspecific and specific immunity, antioxidants, and disease resistance against bacterial and viral pathogens, however, optimization of the dietary requirement of each macro and trace mineral needs to be studied for all edible cultivable aquatic species.

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