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Availability of Minerals in Fish Meal to Fish

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Abstract

Recent investigations on mineral nutrition in fish have demonstrated that the bioavailability of minerals contained in fish meal varies among species. The bioavailability of phosphorus in fish meal appears to correlate with the presence of acidic gastric juice in the stomach, because it is low in stomachless fish like common carp, and high in fish with a stomach such as rainbow trout. On the other hand, the bioavailability of magnesium in white fish meal to fish is very low. Since the content of trace minerals and their inorganic forms vary in different kinds of fish meal, their bioavailability will also vary due to the kind of fish meal. The bioavailability of zinc contained in various fish meals depends on the tricalcium phosphate content of the meal in the case of rainbow. trout. Zinc availability is lowest in white fish meal which contains the highest level of tricalcium phosphate, and slightly better in brown fish meal which contains less tricalcium phosphate. On the other hand, the effect of tricalcium phosphate on the availability of zinc to stomachless fish like the common carp is less than to fish with a stomach such as the rainbow trout. The availability of manganese in fish meal is relatively high for carp and unaffected by the tricalcium phosphate levels in the fish meal.

Introduction

Our knowledge of the mineral nutrition of fish is one of the least advanced areas of fish nutrition. Although many studies have been conducted on osmoregulation, heavy metal toxicity and related physiological functions, only a few of the findings are relevant to nutrition. One of the reasons for the paucity of research in this area is the difficulty of experimentation. Unlike other nutrients, significant amounts of minerals can be absorbed from the surrounding waters making it difficult to properly control the dietary intake of the mineral being studied. This is a particular problem for studies of trace minerals, such as iron, zinc, manganese, copper and cobalt, and for trials with marine species where the rearing water contains significant quantities of most minerals. Red seabream only require supplemental iron, potassium and phosphorus in the diet. The remaining minerals are apparently absorbed from the rearing water. Interactions between minerals also complicate the assessment of dietary requirements.

About twenty inorganic elements are required to meet the structural and metabolic functions of vertebrates. Mineral metabolism differs from that of most other nutrients because they are neither produced nor consumed by the organism. Furthermore, most vertebrates are only able to exercise minimal regulation of the levels of minerals which are absorbed from the food. Nevertheless, most species have the ability to regulate the concentration of ions in their body fluids and thus maintain a constant internal milieu. This is achieved in fish by ionic and osmotic regulatory processes in the kidney and gills.

Most studies on the mineral requirements of fish have been conducted using semipurified diets. Practical formulated fish feeds usually contain relatively high levels of fish meal as a protein source and high amounts of various minerals are derived from fish meal. However, recently it has been demonstrated that the bioavailability of various minerals contained in certain feed ingredients, such as fish meal, is relatively low due to the interactions between minerals. The purpose of this paper is to review the recent information on bioavailability to fish of various kinds of minerals including the trace minerals contained in fish meal.

Mineral Requirements of Fish

Minerals required by fish are calcium, magnesium, phosphorus, and a number of trace elements such as copper, iodine, iron, manganese, selenium and zinc. The mineral requirements of various fish species and their deficiency symptoms are summarized in Tables 1 and 2.

Of all the minerals, phosphorus is arguably one of the most important mainly because of its high requirement for growth and

Table 1. Mineral deficiencies in fish.

Mineral	Common carp	Rainbow trout	Others
P	poor growth; skeletal abnormality; low feed efficiency; low ash in whole body and vertebrae; high lipid content	poor growth; skeletal abnormality; low ash in bone	poor growth and skeletal abnormality in chum salmon; poor growth, poor feed efficiency, and low ash in channel catfish
Mg	poor growth; high mortality; sluggishness and convulsions; high Ca content in bone	poor growth; high mortality; sluggishness and convulsions; high Ca content in bone; skeletal abnormality; renal calcinosis	poor growth, high mortality, and anorexia in channel catfish
Zn	poor growth; high mortality; erosion of fins and skin; low Zn and Mn content in bone	poor growth; high mortality; erosion of fins and skin; cataract; dwarfism; low Zn and Mn content in bone	cataract in *Oncorhynchus masou*; dwarfism in Japanese eel; anorexia and poor growth in channel catfish
Mn	poor growth; dwarfism; skeletal abnormality; high mortality; low Ca, Mg, P, Zn, Mn content in bone	poor growth; dwarfism; skeletal abnormality; cataract; low Zn, Mn content in bone	dwarfism in Japanese eel;
Cu	poor growth	poor growth	dwarfism in Japanese eel
Co	poor growth		
Fe	anemia		poor growth in Japanese eel; anemia in red sea bream
I			poor growth and high mortality in chum salmon; dwarfish in Japanese eel
Al			dwarfish in Japanese eel
Ca			poor growth in Japanese eel and channel catfish

Table 2. Mineral requirements of fish.

Mineral	Common carp	Rainbow trout	Others
P	0.6-0.7%	0.7-0.8%	0.68% for red sea bream 0.33-0.45% for channel catfish 0.58% for Japanese eel 0.9-1.1% for Ayu fish 0.5-0.6% for chum salmon 0.8-1.0% for *Oreochromis niloticus*
Mg	0.04-0.05%	0.05-0.07%	0.04% for Japanese eel 0.04% for channel catfish
Zn	15-30 $\mu g \cdot g^{-1}$	15-30 $\mu g \cdot g^{-1}$	10 $\mu g \cdot g^{-1}$ for *Oreochromis niloticus* 20 $\mu g \cdot g^{-1}$ for channel catfish
Mn	13 $\mu g \cdot g^{-1}$	13 $\mu g \cdot g^{-1}$	12 $\mu g \cdot g^{-1}$ for *Oreochromis niloticus*
Cu	3 $\mu g \cdot g^{-1}$	3 $\mu g \cdot g^{-1}$	3-4 $\mu g \cdot g^{-1}$ for *Oreochromis niloticus*
Fe	150 $\mu g \cdot g^{-1}$		170 $\mu g \cdot g^{-1}$ for Japanese eel 150 $\mu g \cdot g^{-1}$ for red sea bream
Ca			0.27% for Japanese eel
Se			0.03-0.04 $\mu g \cdot g^{-1}$ for Atlantic salmon (with Vitamin E)
I			0.6 $\mu g \cdot g^{-1}$ for 0.5-8.5 g chinook salmon 1.1 $\mu g \cdot g^{-1}$ for 8.5-50 g chinook salmon

bone mineralization and also lipid and carbohydrate metabolism. Certainly the levels of phosphorus required are the highest of all the inorganic ions with dietary inclusions of 0.5-0.9% of available phosphorus being required for most fish species. Generally, phosphorus requirements are not affected by dietary calcium levels (Andrews et al. 1973; Lovell 1978; Ogino and Takeda 1976, 1978; Ogino and Yang 1979; Sakamoto and Yone 1973, 1978b, 1979c; Watanabe et al. 1980a; Wilson et al. 1982). In controlled experiments, the growth of both common carp and rainbow trout have been shown to correlate positively with dietary phosphorus levels but not with calcium levels. However, for most fish species it is difficult to study the effects of calcium deficiency because calcium is actively absorbed from the water by the gills.

In addition to being a component of bone, magnesium occurs in many metalloenzymes and during magnesium deficiency many metabolic functions are affected. Apart from general symptoms such as reduced weight gain and poor food conversion, magnesium deficiency in rainbow trout leads to renal calcinosis and a flexibility of the muscle, due in part to an increase in extracellular fluid volume (Cowey et al. 1977; Knox et al. 1981a). The magnesium requirement of rainbow trout is 0.05-0.07% and of common carp is 0.04-0.05% (Ogino and Chiou 1976; Ogino et al. 1978; Knox et al. 1983) of the diet. However, Sakamoto and Yone (1979a) reported that magnesium supplementation to the diet for red sea bream is not essential when the magnesium exists at a level exceeding 12 mg per 100 g diet.

Zinc is also a component of metalloenzymes (superoxide dismutase, carboxypeptidase). Thus, many metabolic functions are affected by a deficiency of zinc. In rainbow trout, the zinc requirement is normally met by dietary levels of 15-30 $mg{\cdot}kg^{-1}$ diet (Ogino and Yang 1978, 1979), although larger amounts may be required to prevent calcium antagonism under certain circumstances. Dietary zinc levels of up to several hundred milligrams per kilogram of diet do not seem injurious to rainbow trout (Wekell et al. 1983).

Dietary iron is essential to maintain normal hemoglobin content, hematocrit value and mean corpuscular diameter. A minimum dietary iron concentration of 150 $mg{\cdot}kg^{-1}$ is required to prevent iron deficiency symptoms such as hypochromic, microcytic anemia and anisocytosis in red seabream and common carp (Sakamoto and Yone 1978a, 1979b).

Manganese deficiency in rainbow trout gives rise to abnormal curvature of the backbone and malformation of the tail. Higher growth rates of both rainbow trout and common carp were obtained when they were fed diets with a manganese content of 12-13 $mg{\cdot}kg^{-1}$ diet than when the manganese level was 4 $mg{\cdot}kg^{-1}$ diet (Ogino and Yang 1980). On the other hand, Gatlin and Wilson (1984b) and Knox et al. (1981b) reported that the manganese derived only from casein diets was apparently adequate to support good growth and feed conversion efficiency with channel catfish and rainbow trout, respectively, but bone manganese content increased as the level of supplemental manganese increased.

Availability of Minerals in Fish Meal

Many feed ingredients contain various types of minerals in relatively high amounts. As shown in Table 3, this is especially true

Table 3. Proximate and mineral compositions of fish meals produced during 1981-1986.

Lot number		White fish meal 1	2	3	4	5	6	7	8	9	10	Brown meal 1	2
Moisture	(%)	8.6	7.8	7.9	9.5	7.5	7.4	9.2	9.2	10.4	12.6	11.2	6.2
Crude protein	(%)	69.5	66.9	67.3	64.0	65.2	67.3	68.1	68.1	65.9	63.6	66.8	71.1
Crude lipid	(%)	9.4	10.2	9.1	9.8	10.2	8.7	10.1	14.8	12.6	9.4	10.8	11.1
Crude ash	(%)	14.0	16.8	17.1	17.6	18.2	18.4	12.6	13.6	13.9	16.9	14.5	15.1
K	($mg \cdot g^{-1}$)	4.4	4.5	4.6	6.1	5.1	4.4	3.7	3.6	4.4	3.1	13.4	3.5
Na	($mg \cdot g^{-1}$)	6.0	5.3	5.7	9.7	7.9	5.4	6.1	6.1	6.5	8.4	8.3	3.2
Ca	($mg \cdot g^{-1}$)	35.5	63.8	61.7	57.8	64.0	61.4	21.5	21.5	44.6	52.2	34.4	44.3
Mg	($mg \cdot g^{-1}$)	1.9	1.3	2.7	2.6	2.5	2.0	2.1	2.1	2.0	2.8	2.0	2.0
P	($mg \cdot g^{-1}$)	28.6	42.8	36.5	28.8	29.9	41.5	23.8	24.8	25.8	29.3	24.7	27.3
Zn	($\mu g \cdot g^{-1}$)	65.6	61.2	69.5	68.9	72.2	68.2	63.5	62.3	61.0	71.3	100.7	141.8
Mn	($\mu g \cdot g^{-1}$)	4.0	4.3	4.9	4.5	4.7	4.2	4.5	4.0	3.8	5.2	9.2	11.1
Cu	($\mu g \cdot g^{-1}$)	1.9	2.5	2.4	1.8	1.6	2.4	2.7	2.0	2.1	11.5	6.2	5.4
Fe	($\mu g \cdot g^{-1}$)	86.4	90.9	131.0	119.8	161.9	100.0	104.5	104.5	157.1	97.3	289.3	239.5

for fish meal, a major protein source for fish diets. However, recent investigations on mineral nutrition in fish have demonstrated that the bioavailability of certain minerals contained in fish meal is relatively low and differs among species.

Phosphorus

The availability of inorganic phosphorus depends on the solubility of the salt concerned. Thus, phosphorus from tricalcium phosphate is less available than that from the more soluble mono- and dicalcium phosphates, particularly in stomachless fish such as common carp (Table 4) (Ogino et al. 1979). It has also been shown that the availability of phosphorus contained in fish meal is fairly low

Table 4. Availability of various types of phosphate to common carp and rainbow trout.

Phosphate	Common carp (%)	Rainbow trout (%)
Monocalcium phosphate	94	94
Dicalcium phosphate	46	71
Tricalcium phosphate	13	64
Phosphate in white fish meal	10-26	60-72
Phospbate in brown fish meal	13-33	70-81

in carp (0-33%) compared to rainbow trout (60-81%). The supplementation of monosodium phosphate to fish meal diets resulted in an increase in the growth response of common carp (Takamatsu et al. 1975; Shitanda et al. 1979). This difference in phosphorus availability from fish meal between carp and rainbow trout is considered to be due to presence of the acidic gastric juices in the stomach of the latter. Phosphorus in fish meal exists mainly in the form of insoluble hydroxyapatite $[Ca_{10}(PO_4)_6(OH)_2]$ originating from the hard tisses such as bones and scales. Accordingly, it is presumed that common carp cannot dissolve the phosphorus in fish meal, and consequently require supplemental soluble phosphorus in the feed. In carp culture, the poor absorption of phosphorus from fish meal leads to its accumulation in the pond water from the feces. The phosphorus slowly dissolves and together with the ammonia excreted by the carp produces extensive eutrophication. No satisfactory solution has been found to control this pollution and subsequent phytoplankton production, whilst at the same time providing suitable dietary levels of phosphorus in the fish. The percentage absorption of phosphorus in fish meal is approximately 30% in black seabream (Yone and Toshima 1979), 71% in chum salmon and 65% in *Oreochromis niloticus* (Watanabe et al. 1980a, 1980b).

Magnesium

As shown in Table 3, both white fish meal and brown meal contain magnesium in relatively high amounts. Thus, a diet containing fish meal as a protein source contains adequate magnesium to satisfy the level required by fish (0.04-0.07% in diet). However, feeding a diet without supplemental magnesium resulted in poor growth and feed efficiency together with deficiency symptoms. In order to clarify the availability of magnesium in fish meal, Satoh et al. (1983a, 1983b) determined the effect of the deletion of magnesium from the mineral supplement in a white fish meal diet on the growth and mineral composition of vertebrae in common carp and rainbow trout. The basal diet contained 0.14% magnesium derived from white fish meal, or about twice the level required by both species. Feeding the diet resulted in poor growth and greatly affected the mineral composition of vertebrae in both species. The ratio of calcium to magnesium in the vertebrae of fish fed the white fish meal diet without supplemental magnesium was greater than 50. A rate of 50 or less has been reported to indicate normal status of fish receiving adequate levels of dietary magnesium (Ogino and Chiou 1976; Ogino et al. 1978). Thus, the magnesium in fish meal is only poorly absorbed by these fish.

Trace minerals

Some of the trace minerals in fish meal have also been suggested to have low availability to fish. In long-term feeding trials with rainbow trout, feeding a fish meal diet without a supplement of trace minerals resulted in reduced growth and low feed efficiency (Watanabe et al. 1980c). Fish fed the deficient diet exhibited lens cataracts and short-body dwarfism after 14 weeks. The incidence of cataracts and dwarfism was 86% and 31%, respectively, at the end of the 18th week. The total deletion of trace minerals from a fish meal diet also caused cataracts along with exophthalmus and depressed growth in chum salmon fry during a 13-week study. Short-body dwarfism was not observed in the chum salmon fry.

Trace minerals have also been shown to be important for the reproduction of rainbow trout (Takeuchi et al. 1981). Eggs from fish fed a fish meal diet without supplemental trace minerals were markedly lower in both percentage of eyed eggs and hatchability, although there was no difference in proximate composition of eggs due to the difference in diets. The contents of manganese, zinc and iron in the bones and manganese in eggs were significantly lower in the fish fed the diet without supplemental trace minerals than those in fish receiving a commercial diet. Based upon these results, it was concluded that the availability of trace minerals in fish meal was relatively low and that a supplement of trace minerals is indispensable for diets containing fish meal for normal growth and reproduction of rainbow trout.

The content of zinc in fish meal is high (Table 3). A diet containing fish meal without supplemental zinc includes about 35-45 μg of zinc per g of diet, which is adequate. However, deletion of zinc from the mineral supplement in a white fish meal diet induced eye lens cataract in rainbow trout and this symptom was effectively improved by supplementation of available zinc to the diet (Ketola 1979). These results were supported by those obtained by Satoh et al. (1983a) who conducted a long-term feeding study to determine the availability of various trace minerals contained in fish meal to rainbow trout. Feeding the fish meal diet without supplemental zinc resulted in lens cataract (100% of fish) along with short-body dwarfism and depressed growth (Figs. 1 and 2). The effect of zinc deletion was found to be very similar to that of total trace mineral deletion. The deletion of manganese also resulted in cataracts (80% of fish), but did not affect the growth of the fish. Deletion of zinc from the mineral supplement in the fish meal diet reduced levels of manganese and copper in vertebrae, whereas the deletion of

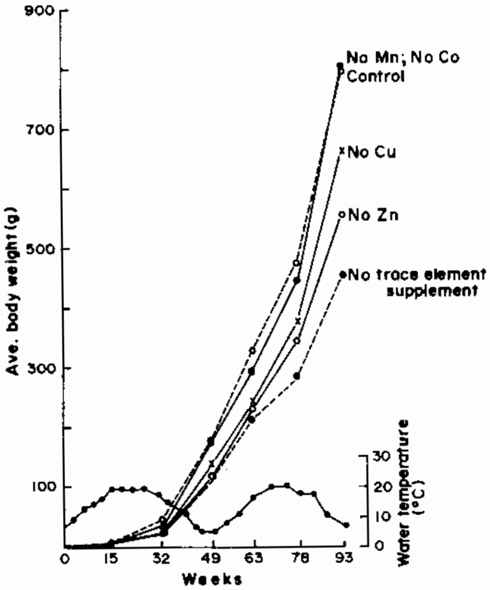

Fig. 1. Growth of rainbow trout fed fish meal diets without one or more supplementary trace elements, Zn, Mn, Cu or Co, for 93 weeks.

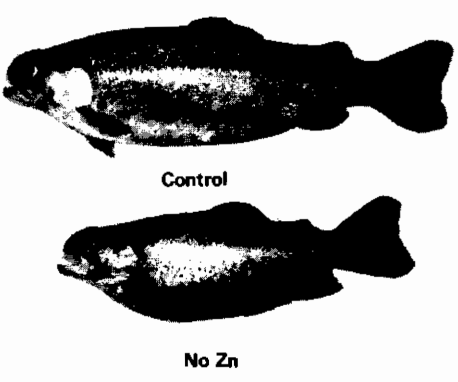

Fig. 2. Rainbow trout fed respectively on the control diet and the fish meal diet without supplement of Zn showing dwarfism.

manganese, copper or cobalt reduced the level of zinc in vertebrae, suggesting interactions between these trace minerals in fish. These results indicate that supplemental zinc, manganese and copper are essential for rainbow trout diets, especially when they contain fish meal as a protein source.

Similar results were also obtained in common carp (Satoh et al. 1983b). Feeding a fish meal diet without supplemental manganese resulted in lens cataracts (70% of fish) along with short-body dwarfism (90%) and depressed growth (Figs. 3 and 4). Deletion of zinc, copper or cobalt from the mineral supplement also resulted in

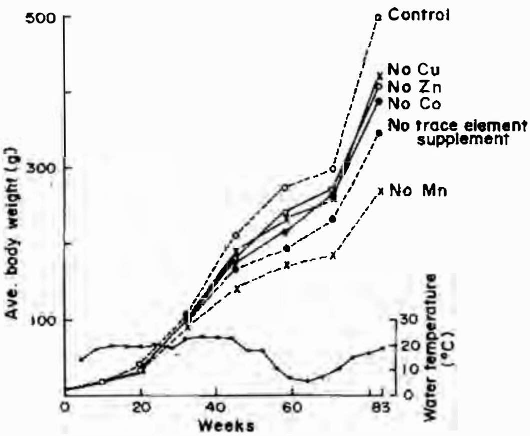

Fig. 3. Growth of common carp fed fish meal diets without one or more supplementary trace elements, Zn, Cu or Co, for 83 weeks.

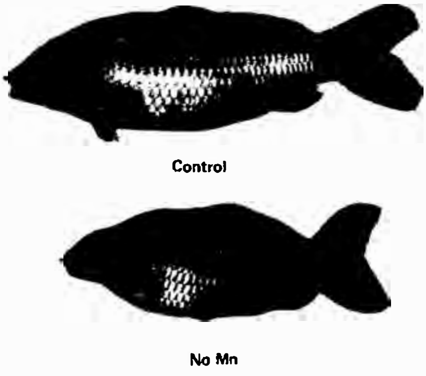

Fig. 4. Common carp fed respectively on a control diet and fish meal diet without supplement of manganese showing dwarfism.

cataracts (40-70%) and reduced growth. However, short-body dwarfism was not induced by the deletion of zinc, quite different from the case of rainbow trout. The mineral composition of vertebrae was also affected by these treatments. The deletion of manganese resulted in reduced levels of crude ash, calcium, manganese, phosphorus and zinc in vertebrae.

Deletion of both zinc and manganese from the mineral supplement in a fish meal diet resulted in the lowest growth of rainbow trout (Satoh et al. 1983c). The deletion of zinc alone or simultaneously with copper or manganese affected the growth of fish more severely than the total deletion of the mineral supplement. However, the highest incidence of lens cataracts and short-body dwarfism was caused by the single deletion of zinc. Another experiment was conducted to examine the availability of trace minerals in fish meal by increasing the level of fish meal in the diet thus increasing the dietary amount of trace minerals derived from fish meal. Growth and feed efficiency of rainbow trout were not improved by the treatment, confirming the low availability of trace minerals in fish meal to rainbow trout. However, the poor growth and low feed efficiency were later found to be mainly due to a low availability of zinc which was greatly affected by tricalcium phosphate and the availability of manganese was relatively high in both common carp and rainbow trout.

Satoh et al. (1987a) reported that the mineral composition of common carp gonads was significantly affected by zinc or manganese deletion from the mineral supplement in a fish meal diet. This may suggest that the quality of eggs in terms of the rate of eyed eggs and hatchability is affected by the mineral status of the broodstock. Similar results have previously been observed in rainbow trout (Takeuchi et al. 1981). Thus, trace minerals should be provided in practical fish meal diets for normal growth and reproduction of fish. Hardy et al. (1984) reported that additional fortification of broodstock salmon diets with copper, cobalt, iron and manganese over standard production diet levels did not increase egg levels at spawning or the maternal soma levels of these elements, although an additional supplement of zinc resulted in slightly increased amounts of this mineral in the ovaries of female salmon. Optimum supplemental levels of these trace minerals will mainly depend on the level of dietary tricalcium phosphate derived from fish meal and on the fish species, as described in the next section.

Minimum supplemental levels of zinc and manganese in fish meal diets for rainbow trout and common carp

The availability of zinc contained in white fish meal and in various zinc compounds ($ZnSO_4$, $ZnNO_3$, $ZnCl_2$ and $ZnCO_3$) was examined to determine a minimum supplemental zinc level to white fish meal-based diets for normal growth of rainbow trout (Satoh et al. 1987b). Deficiency symptoms were effectively improved by the addition of zinc at a level greater than 40 $\mu g \cdot g^{-1}$ diet with $ZnSO_4$ or $ZnNO_3$ (Table 5). When growth was compared among rainbow trout receiving diets supplemented with different zine compounds at a level of 20 $\mu g \cdot g^{-1}$ Zn in the diet, it was highest in rainbow trout fed a diet supplemented with $ZnSO_4$, medium in fish fed a diet with $ZnNO_3$, and lowest in those fed $ZnCl_2$. At a supplemental zinc level of 40 $\mu g \cdot g^{-1}$ Zn, growth was lowest in fish fed a diet with $5ZnO \cdot 2CO_3$. Short-body dwarfism was recognized in fish fed diets containing supplemental zinc at a level less than 20 $\mu g \cdot g^{-1}$ diet regardless of the form of zinc. The dwarfism was found to be effectively prevented by addition of zinc at a level more than 40 $\mu g \cdot g^{-1}$ $ZnSO_4$ or $ZnNO_3$. But supplement of zinc with $5ZnO \cdot 2CO_3$ at the same level did not prevent completely the appearance of dwarfism. The zinc content of vertebrae was lowest in fish fed the diet without supplemental zinc and was proportional to dietary zinc levels, reaching a plateau at supplemental zinc levels greater than 40 $\mu g \cdot g^{-1}$ diet (Fig. 5). The results also indicate that the availability of zinc in white fish meal was very low. The supplemental level of greater than 40 $\mu g \cdot g^{-1}$ of zinc

Table 5. Apparent digestibility of Zn and available Zn content in the fish meal diet for rainbow trout.

Diet	No supplementary Zn	40 $\mu g \cdot g^{-1}$ supplementary Zn
Dietary Zn level ($\mu g \cdot g^{-1}$)	39.5	80.2
Apparent digestibility (%)	0	18.6
Available Zn content ($\mu g \cdot g^{-1}$)	0	14.9

in the diet is higher than the zinc requirement of rainbow trout (15-30 μg·g^{-1} diet) as determined with semipurified diets by Ogino and Yang (1978).

One of the marked differences between the semipurified diets and the white fish meal diets used in these experiments is the higher ash content in the fish meal diets. This is due to high amounts of hydroxyapatite (mainly in the form of tricalcium phosphate) in white

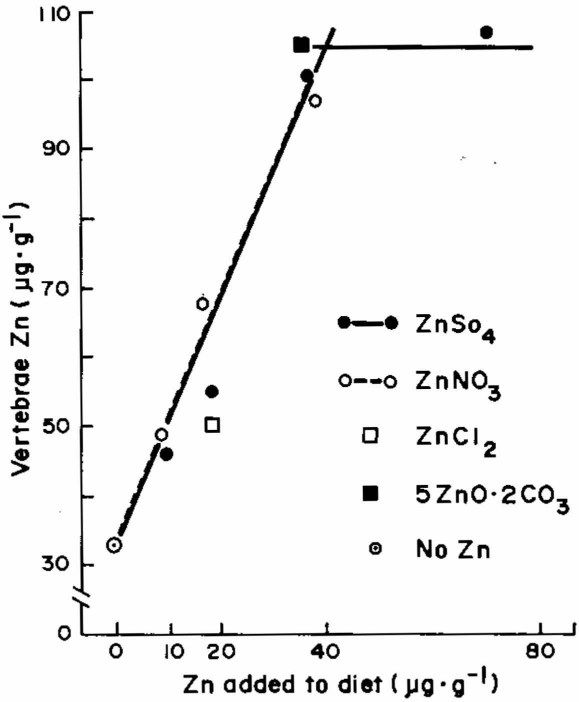

Fig. 5. Effect of dietary Zn levels and Zn forms on the Zn content of vertebrae in rainbow trout.

fish meal derived from hard tissues such as bone. Likuski and Forbes (1965) and Forbes et al. (1984) have reported that high levels of dietary calcium and/or phytate reduces zinc bioavailability in rats. Our results suggest that tricalcium phosphate in white fish meal may decrease the availability of zinc in white fish meal diets, leading to an increase in the optimum zinc supplemental level for fish meal diets in comparison to semipurified diets which do not contain tricalcium phosphate. Gatlin and Wilson (1983, 1984a) reported a similar result in channel catfish. The optimum supplemental zinc level for a practical catfish diet containing 42% soybean meal and 11% menhaden fish meal was 150 mg·kg-1 of diet, much higher than the value of 20 mg·kg-1 diet for a semipurified diet. However, these workers attributed the need for additional zinc to the phytic acid content of the practical diet.

Satoh et al. (1987c) examined the availability of manganese contained in white fish meal and the minimum supplemental manganese levels needed for a white fish meal-based diet for normal growth of common carp. The lowest growth rate and the highest incidence of dwarfism were observed in fish receiving a diet without supplemental manganese. Performance was effectively improved by the addition of $MnCl_2$ at a level greater than 10 μg·g-1 of Mn in the diet (Fig. 6). The diet without supplemental manganese contained 3 μg·g-1 Mn in the diet derived mostly from white fish meal. The addition of 10 μg·g-1 Mn in the diet resulted in a total Mn in the diet of 13 μg·g-1, equivalent to the manganese requirement of carp as determined by Ogino and Yang (1980) using semipurified diet. This

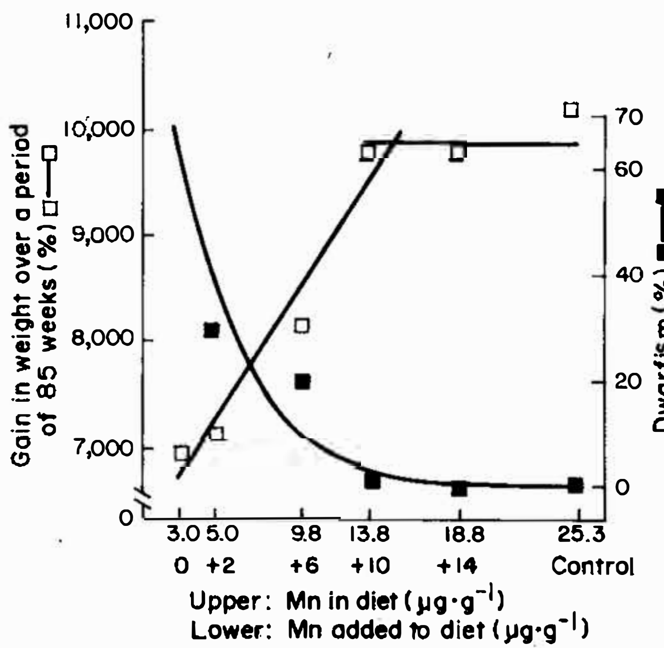

Fig. 6. Effect of Mn levels in white fish meal diets on the per cent weight gain and the appearance of dwarfism in common carp.

level resulted in satisfactory performance in terms of growth, feed efficiency and absence of dwarfism. These results indicate a high availability of manganese in white fish meal to carp.

Satoh et al. (1987c) also examined the availability of various manganese compounds ($MnSO_4$, $MnCO_3$, MnO_2, $MnCl_2$) and found that $MnSO_4$ and $MnCl_2$ were the most suitable sources of manganese for carp. The availability of Mn in MnO_2 and $MnCO_3$ was very low to carp.

Effect of dietary tricalcium phosphate on zinc bioavailability to rainbow trout and common carp

Reduction in the bioavailability of zinc in fish meal-based diets by tricalcium phosphate in the form of hydroxyapatite has been studied by Hardy and Shearer (1985) and Satoh et al. (1987d) using semipurified diets containing different levels of tricalcium phosphate. The former reported that dietary tricalcium phosphate levels in casein-gelatin diets had no significant effect on weight gain but that increased dietary levels of tricalcium phosphate reduced whole body zinc concentration of rainbow trout. The latter authors reported that supplementation of 7% tricalcium phosphate, a level equivalent to that contained in a white fish meal-based diet, to an egg albumin diet greatly reduced the growth rate and feed efficiency which were not improved by the addition of 40 $\mu g \cdot g^{-1}$ Zn in the diet (Fig. 7). The

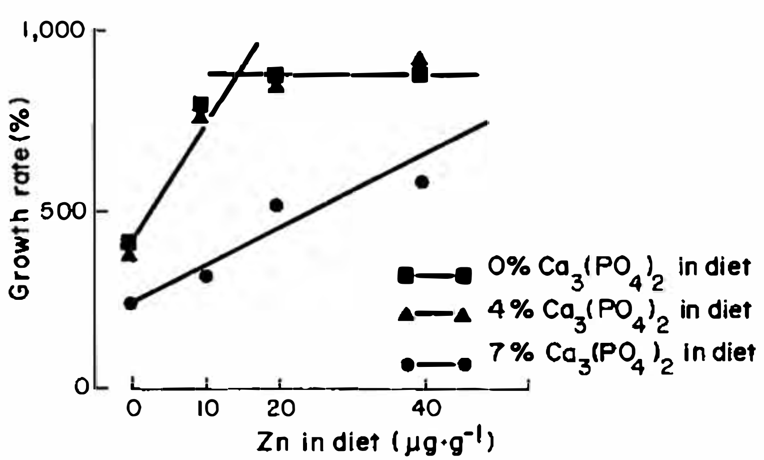

Fig. 7. Combined effect of dietary tricalcium phosphate and Zn levels on growth rate in rainbow trout.

availability of zinc was greater than 93% in the tricalcium-free diets, however, it was markedly reduced by increasing level of dietary tricalcium phosphate (Fig. 8). Zinc in the 7% tricalcium phosphate diet was found to be essentially unavailable to rainbow trout. Furthermore, it was found that supplementation of 80 $\mu g{\cdot}g^{-1}$ Zn in the diet was necessary for the diet containing 7% tricalcium phosphate to obtain the same growth rate and feed efficiency, along with similar whole-body mineral composition, as fish fed a tricalcium

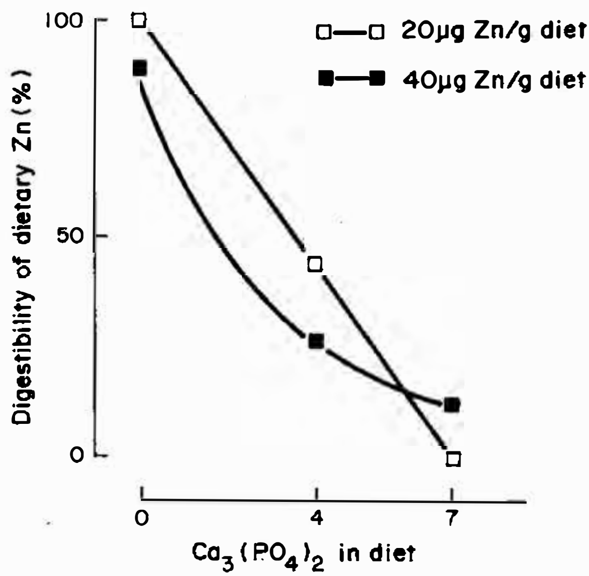

Fig. 8. Combined effect of dietary Zn and tricalcium phosphate levels on digestibility of Zn in rainbow trout.

phosphate-free diet containing 40 $\mu g{\cdot}g^{-1}$ Zn in the diet. These results demonstrate that tricalcium phosphate greatly reduces the availability of zinc and that a minimum supplemental level of 40 $\mu g{\cdot}g^{-1}$ Zn in the diet was necessary for white fish meal-based diets which contain about 7% tricalcium phosphate and 40 $\mu g{\cdot}g^{-1}$ of Zn. Similar results have been obtained by Lall and Hines (unpublished data) on the availability of manganese in fish meal to Atlantic salmon and brook trout.

Phytic acid in plant protein sources, such as soybean meal or cotton seed meal, is known to chelate strongly divalent minerals such as zinc to form insoluble phytates in the intestinal lumen, resulting in lowered zinc availability. Spinelli et al. (1983) reported that phytate *per se* at a level of 5 $g{\cdot}kg^{-1}$ in the diet did not apparently reduce the bioavailability of zinc as reflected by the zinc content in blood, liver and kidney of rainbow trout. On the other hand, Richardson et al. (1985), who fed semipurified diets to chinook salmon containing various levels of calcium, phosphorus, zinc and sodium phytate, found that high dietary phytic acid content (25.8 $g{\cdot}kg^{-1}$) depressed fish growth, feed and protein conversion and increased mortality, promoted cataract formation (even at a zinc level of 50 $mg{\cdot}kg^{-1}$) and that calcium (or phosphorus) at 51 $g{\cdot}kg^{-1}$ exacerbated the effects of high dietary zinc on cataract incidence. They concluded that calcium and/or phosphorus reduced zinc bioavailability when the diet contained 50 $mg{\cdot}kg^{-1}$ of zinc and 25.8 $g{\cdot}kg^{-1}$ of phytic acid.

On the other hand, phosphorus and/or calcium in the form of tricalcium phosphate is poorly absorbed by stomachless fish like carp. This would suggest a lesser effect of tricalcium phosphate on the availability of zinc to carp. This has also been studied by Satoh et al. (unpublished data). They found that the availability of zinc in terms of growth and feed efficiency was not affected by dietary tricalcium phosphate levels. However, the whole body and vertebrae content of zinc and manganese was reduced by an elevation of dietary tricalcium phosphate.

Availability of zinc and manganese contained in various types of fish meal to rainbow trout and common carp

Since the content of trace minerals and their inorganic forms may vary in fish meals as mentioned above, their bioavailability to fish also varies due to kind of fish meal. In this context, the availability of zinc contained in four kinds of fish meal (white fish meal, brown fish meal, sardine meal with or without solubles) was examined by feeding various diets containing these fish meals as a protein source to rainbow trout (Satoh et al. 1987d). The effect of zinc deletion from the mineral supplement in these fish meal diets on low growth, appearance of dwarfism and lens cataract, and zinc content of vertebrae was highest in fish fed white fish meal diet which contains the highest level of tricalcium phosphate. The effect was less severe in fish fed the other fish meal diets which were lower in tricalcium phosphate.

On the other hand, the manganese contained in these four kinds of fish meal was found to be highly available to carp (Satoh et al., in press). the manganese requirement of carp was satisfied by the manganese derived from each fish meal along with the supplemental manganese. No difference was observed in the performance of fish fed these diets and those fed the control diet. The availability of manganese was not effected by the tricalcium phosphate content of fish meal, quite different from the case of zinc.

Discussion

As mentioned above research on the mineral requirement of fish has been advancing rapidly. However, many questions remain in this area. For example, additional studies are needed on the interaction between certain minerals that may alter their bioavailability. Mineral availability data are needed for the various feed ingredients which have potential use in fish feed. Feeds need to be formulated to reduce the amount of undigested nutrients which are excreted by the fish and serve as potential pollutants, such as phosphorus. Finally, there is a need for the development of a simple method for the determination of the available mineral content in the diet.

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