Nutrient requirements of catfishes (Siluroidei)

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Abstract

The channel catfish (*Ictalurus punctatus*) is the most widely cultured foodfish in the U.S., thus most of the nutrient requirement data are available for this species. Qualitatively, about 40 nutrients have been identified as necessary for the normal metabolic function of the channel catfish with quantitative requirement values available for about 30 nutrients including amino acids, fatty acids, minerals and vitamins. Additional information is available on protein and energy requirements, digestible protein and energy coefficients as well as amino acid availability values. Thus adequate nutritional information is available to formulate high quality practical channel catfish feeds.

Only limited nutrient requirement data are available for the other Siluroidei species. Some requirement data have been reported for a few species from Africa (*Clarias gariepinus*, *C. isheriensis*, *Heterobranchus longifilis* and *H. bidorsalis*), Asia (*Clarias batrachus*, *C. macrocephalus*, *C. fuscus* and *Heteropneustes fossilis*) and Europe (*Silurus glanis*). The available requirement data will be summarized and compared with the requirement data for the channel catfish. Some variation does appear to exist in optimum dietary protein levels, essential fatty acid requirements, and lipid vs carbohydrate utilization.

Keywords: Protein, energy, fatty acid, carbohydrates, minerals, vitamins, warmwater fish, fish farming.

Les besoins nutritionnels des poissons-chats (Siluroidei).

Résumé

La barbue de rivière ou poisson chat américain (*Ictalurus punctatus*) est l'espèce de poisson dont l'élevage, à des fins culinaires, est le plus répandu aux États-Unis, c'est pourquoi les besoins nutritionnels de cette espèce sont connus, pour la plupart. Qualitativement, près de 40 nutriments ont été reconnus nécessaires au bon fonctionnement métabolique de ce poisson. Quantitativement, les valeurs correspondant à ces besoins ont été déterminées pour presque 30 d'entre eux dont les acides aminés, les acides gras, les minéraux et les vitamines. Des informations complémentaires sont disponibles sur les besoins protéino-énergétiques, les coefficients de protéine et d'énergie digestible ainsi que sur la disponibilité digestive des acides aminés. Pratiquement, ces informations permettent la formulation en routine d'aliments de qualité qui répondent aux exigences de l'espèce.

Pour les autres espèces de Siluroidei, la connaissance de leurs besoins nutritionnels est plus restreinte. Quelques données ont pu être obtenues sur des espèces originaires d'Afrique (*Clarias gariepinus*, *C. isheriensis*, *Heterobranchus longifilis* et *H. bidorsalis*), d'Asie (*Clarias batrachus*, *C. macrocephalus*, *C. fuscus* et *Heteropneustes fossilis*) et d'Europe (*Silurus glanis*). Les informations disponibles sur leurs besoins nutritionnels sont récapitulées et comparées aux données disponibles pour la barbue de rivière. Quelques points de divergences apparaissent pour la concentration protéique optimale de l'aliment, les besoins en acides gras essentiels et l'utilisation réciproque des lipides et des glucides.

Mots-clés : Protéines, énergie, acides gras, glucides, minéraux, vitamines, poissons tropicaux, élevage piscicole.

INTRODUCTION

The channel catfish (*Ictalurus punctatus*) is the most widely cultured foodfish in the U.S., thus most of the nutrient requirement data for finfish are available for this species. Qualitatively, about 40 nutrients have been identified as necessary for the normal metabolic function of the channel catfish with quantitative requirement values available for about 30 nutrients including amino acids, fatty acids, minerals and vitamins. Additional information is available on protein and energy requirements, digestible protein and energy coefficients as well as amino acid availability values. Thus adequate nutritional information is available to formulate high quality practical channel catfish feeds.

Only limited nutrient requirement data are available for the other Siluroidei species. Some requirement data have been reported for a few species from Africa (*Clarias gariepinus*, *C. isheriensis*, *Heterobranchus longifilis* and *H. bidorsalis*), Asia (*Clarias batrachus*, *C. macrocephalus*, *C. fuscus* and *Heteropneustes fossilis*) and Europe (*Silurus glanis*). The available data are summarized herein and compared with the requirement data for the channel catfish. Some variation does appear to exist in optimum dietary protein levels, essential fatty acid requirements and lipid vs carbohydrate utilization.

NUTRIENT REQUIREMENTS

Protein and amino acids

Estimations of the protein requirement of channel catfish have been based on total weight gains of fish fed practical and purified diets. These studies have indicated optimum dietary levels of crude protein ranging from 25 to 50%. These differences are probably due to differences in size of the fish, water temperature, natural food available in the ponds, fish stocking density, daily feed allowance, amount of nonprotein energy in the feed, and the quality of the dietary protein.

Studies in controlled environments have indicated that the protein requirement of channel catfish ranges from 25 to 36%, depending on fish size. When 114 g or larger fish were fed to satiation, 25% dietary protein was adequate for maximum growth. However, when the feeding rate was restricted, higher protein levels were beneficial (Page and Andrews, 1973). Smaller fish required higher protein levels and grew best at 35% dietary protein. Maximum growth rates were observed in small (7 g) channel catfish fed purified diets containing 36% protein and 1.4 $MJ.100\ g^{-1}$ diet (Garling and Wilson, 1976). However, maximum protein deposition ($g.kg^{-1}.day^{-1}$) was observed in fish fed 24% protein and 1.2 $MJ.100\ g^{-1}$ diet. Gatlin *et al.* (1986) have determined the protein requirement for maintenance and maximum growth of small channel catfish fed purified diets. The maintenance protein requirement was found to be 1.00 to 1.32 g protein.kg body $weight^{-1}.day^{-1}$ and the value for maximum growth was 8.75 g protein.kg body $weight^{-1}.day^{-1}$. This latter value indicates that a 29% protein diet should be adequate for channel catfish when fed at a feeding rate of 3% of body $weight.day^{-1}$. Most commercial channel catfish feeds contain 32% protein. However, some channel catfish farmers use 28, 30 and 36% protein feeds.

Recommended dietary protein levels for other Siluroidei species are generally higher than for channel catfish (*table* 1). The best growth responses have been obtained with feeds containing 35 to 50% crude protein (Henken *et al.*, 1986; Hilge and Schwalb-Buchling, 1980). When one considers the daily feeding rate associated with these diets, most of the daily protein

Table 1. – Dietary crude protein and digestible energy (DE) recommendations reported for various catfish species.

Species	Protein %	mg protein $kJ\ DE^{-1}$	Reference
Clarias anguillaris	40		Madu and Tsumba (1989)
Clarias batrachus	39.5	31 [1]	Mollah and Hussain (1990)
Clarias batrachus [2]	30		Chuapoehuk (1987)
Clarias gariepinus	40		Degani *et al.* (1989)
	50	24	Henken *et al.* (1986)
Clarias isheriensis	37	22 [1, 3]	Fagbenro (1992)
Heterobranchus bidorsalis	40	25 [3]	Kerdcheun (1992)
Heterobranchus longifilis	42.5	26	Fagbenro *et al.* (1992)
Heteropneustes fossilis [2]	28-35		Akand *et al.* (1989)
Ictalurus punctatus	32	25	NRC (1993)
Mystus nemurus	42	27 [4]	Khan *et al.* (1993)
Pangasius sutchi [2]	25		Chuapoehuk and Pothissong (1985)

[1] Energy value calculated on proximate analysis basis (Luquet and Moreau, 1989).

[2] Fry.

[3] Gross energy basis.

[4] Digestible protein basis.

requirements range from 15 to 20 g crude protein.kg body weight^{-1}.day^{-1}, but can be as low as 12 (Mollah and Hussain, 1990) or 10 g crude protein.kg body weight^{-1}.day^{-1} (Henken *et al.*, 1986).

Channel catfish have been shown to require the same 10 essential amino acids as other fish (Dupree and Halver, 1970). The quantitative requirements for these essential amino acids are summarized in *table* 2. These requirement values were obtained by feeding graded levels of each respective amino acid in a test diet containing a mixture of casein, gelatin, and amino acids formulated so that the amino acid profile was identical to whole chicken egg protein except for the amino acid being tested. These amino acid test diets had to be neutralized to pH 7.0 for maximum utilization (Wilson *et al.*, 1977). A highly significant correlation was found between the essential amino acid requirement pattern and the content of the same amino acids in whole body tissue of the channel catfish. In addition, no differences were detected in the whole body amino acid composition of channel catfish ranging from 30 to 863 g, which was interpreted to indicate that the amino acid requirements when expressed as a percent of dietary protein should not change with increasing size of the fish (Wilson and Poe, 1985). No gross deficiency signs were detected in the fish fed the various amino acid deficient diets other than a marked reduction in weight gain.

Table 2. – Quantitative amino acid requirements of channel catfish [1].

Amino acid	Requirement	Reference
Arginine	4.3 (1.03/24)	Robinson *et al.* (1981)
Histidine	1.5 (0.37/24)	Wilson *et al.* (1980)
Isoleucine	2.6 (0.62/24)	Wilson *et al.* (1980)
Leucine	3.5 (0.84/24)	Wilson *et al.* (1980)
Lysine	5.1 (1.23/24)	Wilson *et al.* (1977)
	5.0 (1.50/30)	Robinson *et al.* (1980*b*)
Methionine	2.3 (0.46/24)	Harding *et al.* (1977)
Phenylalanine	5.0 (1.20/24)	Robinson *et al.* (1980*a*)
Threonine	2.0 (0.53/24)	Wilson *et al.* (1978)
Tryptophan	0.5 (0.12/24)	Wilson *et al.* (1978)
Valine	3.0 (0.71/24)	Wilson *et al.* (1980)

[1] Requirements are expressed as percent of dietary protein. In parentheses, the numerators are requirements as percent of diet and the denominators are percent total protein in the diet.

The requirement value for methionine in *table* 1 actually represents the total sulfur amino acid requirement since it was determined in the absence of cystine. Cystine can be formed from dietary methionine, whereas methionine cannot be synthesized from cystine. Thus, the total sulfur amino acid requirement can be met by either methionine alone or a proper mixture of methionine and cystine. Cystine was found to be able to replace or spare 60% of the methionine requirement on a millimole sulfur basis (Harding *et al.*, 1977). DL-methionine was found to be utilized as effectively as L-methionine; however, methionine hydroxy analogue was only 26% as effective in promoting growth as L-methionine (Robinson *et al.*, 1978). Tyrosine was found to be able to replace about 50% of phenylalanine to meet the total aromatic amino acid requirement (Robinson *et al.*, 1980*a*).

Early workers were unable to demonstrate the utilization of supplemental amino acids in practical diets for channel catfish (Andrews and Page, 1974; Andrews *et al.*, 1977). Since these earlier studies were conducted before the essential amino acid requirement values were available, it was assumed that the basal diets used may not have been deficient in the amino acid under study. However, some success has been reported on the use of supplemental amino acids by channel catfish. For example, supplemental lysine has been shown to improve weight gain in channel catfish fed peanut meal (Robinson *et al.*, 1980*b*) and cottonseed meal (Robinson, 1991) based diets. Supplemental methionine has also been shown to improve the utilization of soybean meal based diets for channel catfish (Murai *et al.*, 1982).

Quantitative amino acid requirement data are not available for other catfish species. However, some minimum dietary amino acid levels have been proposed for *Clarias gariepinus* based on published data (Coche and Edwards, 1989). A minimum of 1.95% dietary arginine, corresponding to 3.36% of dietary protein, has been recommended for *Silurus glanis* (Toth, 1986). DL-methionine as well as L-lysine supplementation of a soybean meal based diet has been shown to improve growth of *Clarias anguillaris* (Eyo, 1989,1990).

Energy

Actual energy requirements have not been established for the channel catfish. Current recommendations on energy levels used in formulating channel catfish feeds are based on optimum energy to protein ratios. Providing the optimum energy levels in diets for fish is important because inadequate energy will result in the fish utilizing dietary protein for energy rather than for protein synthesis. Excess energy in the diet may result in decreased nutrient intake by the fish or excessive fat deposition. Since digestible energy (DE) values were not available when most of the energy studies were conducted, various workers have used estimated DE values based on physiological fuel values.

To date, most studies have indicated a DE requirement of 26 to 30 mg protein.kJ DE^{-1} (8 to 9 kcal.g protein^{-1}) to be adequate for fingerling and production size channel catfish (Lovell and Prather, 1973; Garling and Wilson, 1976; Winfree and Stickney, 1984; Mangalik, 1986; Masser, 1986). These values are based on studies in which fish were fed practical feeds in ponds (Lovell and Prather, 1973), fingerling size fish fed purified diets in aquaria

(Garling and Wilson, 1976), fry to fingerling size fish fed practical diets (Winfree and Stickney, 1984), various size channel catfish ranging from 3 to 266 g fed to satiation (Mangalik, 1986), and fingerlings fed purified diets at three different water temperatures (Masser, 1986).

As indicated in *table* 1, the optimum protein to energy ratios for other catfish species are similar to that discussed above for the channel catfish, ranging from 20 to 30 mg protein.kJ DE^{-1}. Energy deposition can be as high as 60% of gross energy in *Silurus meridionalis* fed a raw fish diet (Xie and Sun, 1993). Furthermore, a protein conversion efficiency of 60% appears to be maximal for *Clarias gariepinus* (Machiels, 1987). Even if a high protein/energy ration is used, these observations indicate that an important part of the retained energy can be attributed to non-protein energy deposition. In addition, a higher growth rate, induced by using different feeding strategies in *Heterobranchus longifilis*, led to an increase in body fat composition associated with a rather small improvement in protein deposition (Kerdchuen and Legendre, 1991). Thus, special attention is often required in selecting a feeding strategy (feed composition and feeding frequency) to produce the quality of fish desired.

Gatlin *et al.* (1986) have determined the energy requirement of fingerling channel catfish for maintenance and maximum gain. The requirement values were based on weight gain and body composition data from fish fed purified diets at varying daily rations. Energy requirements for maintenance and maximum growth were 62.8 and 72.4 kJ.kg body $weight^{-1}.day^{-1}$, respectively.

Carbohydrates

Channel catfish have been shown to use higher levels of dietary carbohydrate than coldwater or marine fish. Levels of dietary carbohydrate up to 25% have been shown to be utilized as effectively as lipids as an energy source for channel catfish (Garling and Wilson, 1977). Likimani and Wilson (1982) observed that channel catfish fed a high carbohydrate diet exhibited marked stimulation of several lipogenic enzyme activities in both liver and mesenteric adipose tissue. A similar study using coho salmon, *Oncorhynchus kisutch*, failed to demonstrate any stimulatory effect of high dietary carbohydrate on lipogenic enzyme activities in either liver or mesenteric adipose tissue of this fish (Lin *et al.*, 1977). Therefore, it appears that species such as the channel catfish that can readily adapt to high carbohydrate diets and convert the excess energy into lipids are much more efficient in carbohydrate utilization than those fish lacking that ability. Channel catfish utilize high molecular weight carbohydrates, such as starch and dextrin, more readily than disaccharides or simple sugars (Wilson and Poe, 1987).

Dietary carbohydrates have been shown to be used as an energy source by *Hoplosternum littorale* (Moreau *et al.*, 1992). However, the relative rate of carbohydrate digestion was found to be lower in *Clarias gariepinus* than in hybrid tilapia (*Oreochromis nilolicus* × *O. aureus*) (Degani and Revach, 1991). Nevertheless, pancreatic and foregut amylase activity has been reported for *Clarias gariepinus* (Uys and Hecht, 1987). The pancreatic amylase specific activity decreased following a meal whereas the protease activity in the foregut either remained constant or increased (Uys *et al.*, 1987). This observation was explained as a temporary dilution of the amylase by the ingested food and/or a delayed recovery of amylase production by the pancreas. This pattern was not observed in protease activity, however an apparent decrease in protein digestibility has been reported in *Clarias batrachus* when fed high protein diets (greater than 39.95% crude protein) (Singh and Singh, 1992).

Although no specific carbohydrate requirement has been established for fish, growth rates of fingerling channel catfish were reduced when the fish were fed isonitrogenous, isocaloric semipurified diets containing no dextrin, as compared with fish fed diets containing added dextrin (Garling and Wilson, 1977; Likimani and Wilson, 1982). Carbohydrates also serve as the least expensive source of dietary energy and aid in the pelleting quality of practical channel catfish feeds. Therefore, some form of digestible carbohydrate should be included in channel catfish diets. A typical commercial channel catfish feed contains about 25 to 30% carbohydrate.

Lipids and essential fatty acids

Early workers were unsuccessful in establishing an essential fatty acid requirement of channel catfish; however, it has been reported that channel catfish fed diets containing animal fat or fish oil showed better growth than fish fed diets containing vegetable oils (Stickney and Andrews, 1971, 1972; Yingst and Stickney, 1979). These studies indicated that channel catfish could effectively utilize beef tallow (high in oleic acid and low in n-3 and n-6 fatty acids) or menhaden oil [moderate in n-3 highly unsaturated fatty acids (n-3 HUFA)], whereas safflower oil (high in linoleic acid) and linseed oil (high in linolenic acid) were poorly utilized. These workers suggested that the poor response to vegetable oils was due to a limited ability to metabolize linoleic acid or to competitive inhibition of fatty acid synthesis in the presence of high levels of dietary linolenic acid. Stickney *et al.* (1983) suggested that the poor performance of channel catfish fed vegetable oil was due to dietary linolenic acid and not linoleic acid as first theorized. Satoh *et al.* (1989*a*) reported that supplementation with a mixture of methyl esters of n-3 HUFA or cod liver oil (moderate in n-3 HUFA) to a purified diet enhanced growth of channel catfish. However, channel catfish fed a diet containing beef tallow as the sole lipid source had a lower growth rate than fish fed a diet with n-3 HUFA. Fatty acid composition of the liver polar lipid fraction indicated that channel catfish could convert 18:3n-3 to docosahexaenoic acid (22:6n-3). Subsequently, Satoh *et al.* (1989*b*) demonstrated that n-3 fatty acids were essential for the channel catfish. Specifically, these workers found the essential fatty acid requirement to be met by 1.0 to 2.0% 18:3n-3 or 0.5 to 0.75% n-3 HUFA. Therefore, marine fish oil or linseed oil, which are rich sources of either linolenic acid or n-3 HUFA, should be suitable for supplementation in channel catfish feeds. A minimum level of 0.5 to 1% dietary n-3 fatty acids has also been recommended for *Heterobranchus longifilis* fry (Kerdchuen, 1992).

Channel catfish appear to perform well on a wide range of dietary lipid levels. Studies have been conducted in which channel catfish were fed diets containing 15% or more lipid without conclusive evidence as to which level is best for optimum growth. Dietary carnitine has been shown to improve lipid utilization in *Clarias gariepinus* (Torreele *et al.*, 1993) and reduced lipid deposition in muscle and liver of channel catfish (Burtle and Liu, 1994). From a practical viewpoint, lipids should be added to catfish diets as a source of energy. However, there are constraints on the level of dietary lipid that can be used. If the dietary lipid level is too high, undesirable deposits of lipid in edible tissue may occur or deposits of adipose tissue in the visceral cavity may be excessive, which reduces dressout percentage. A second constraint involves the ability of the feed manufacturer to prepare good quality feed pellets. If the supplemented fat level exceeds approximately 5%, some difficulty in producing extruded pellets occurs unless the lipid is sprayed on after pelleting. Normally, fat is sprayed on channel catfish feeds after pelleting to increase dietary energy and to reduce fines. Generally, lipid levels in commercial channel catfish feeds are about 5 to 6%, approximately 3 to 4% contained in the feed ingredients with the remaining 1 to 2% being sprayed on the finished pellets.

Vitamins

The qualitative vitamin requirements of channel catfish have been determined by feeding purified diets deficient in the vitamin under study and comparing various growth parameters and pathology to fish fed nutritionally complete diets. Quantitative vitamin requirements were then determined by feeding graded levels of the vitamin under study in purified diets. The dietary level that resulted in normal weight gain with the absence of any deficiency signs was considered to be the minimum dietary requirement for that specific vitamin. These requirement studies were conducted with small fish in aquaria, thus the requirement values were determined under optimal conditions for the fish. Although these values are assumed to be adequate for larger fish, certain vitamin requirements may be affected by other factors, such as size, age, growth rate and stage of sexual maturity, as well as environmental stressors, such as disease, water temperature and water quality. Additional research is needed to examine this important area of vitamin nutrition of fish. Characteristic deficiency signs and dietary requirement values for each vitamin are summarized in *tables* 3 and 4. The values recommended for channel catfish are often recommended for other catfish species. A level of 60 mg vitamin $C.kg^{-1}$ diet has been reported to be required for optimal growth of *Clarias gariepinus* (Mgbenka, 1991).

A major consideration when formulating feeds for fish is that ascorbic acid is very labile and thus readily destroyed during the manufacturing process, especially in extruded feeds, commonly used for channel catfish. An ethylcellulose-coated ascorbic acid, which improves stability of the vitamin, is therefore generally used to increase retention of the

Table 3. – Vitamin deficiency signs observed in channel catfish [1].

Vitamin	Deficiency signs	Reference
Vitamin A	Exophthalmia, edema, ascites	NRC (1993)
Vitamin D	Low bone ash	Lovell and Li (1978)
Vitamin E	Skin depigmentation, exudative diathesis, muscle dystrophy, erythrocyte hemolysis, splenic and pancreatic hemosiderosis	Murai and Andrews (1974) Lovell *et al.* (1984) Wilson *et al.* (1984)
Vitamin K	Skin hemorrhage, prolonged clotting time	Murai and Andrews (1977)
Thiamin	Dark skin color, neurological disorders	Murai and Andrews (1978*a*)
Riboflavin	Short-body dwarfism	Murai and Andrews (1978*b*)
Pyridoxine	Greenish-blue coloration, tetany, nervous disorders	Andrews and Murai (1979)
Panthotenic acid	Clubbed gills, anemia, and eroded skin, lower jaw, fins, and barbels	Murai and Andrews (1979)
Niacin	Anemia, lesions of skin and fins, exophthalmia	Andrews and Murai (1978)
Biotin	Anemia, skin depigmentation, reduced liver pyruvate carboxylate activity	Robinson and Lovell (1978)
Folic acid	Anemia	Duncan *et al.* (1993)
Vitamin B-12	Anemia	Limsuwan and Lovell (1981)
Choline	Fatty liver	Wilson and Poe (1989)
Inositol	None	Burtle and Lovell (1989)
Vitamin C	Scoliosis, lordosis, reduced bone collagen, internal and external hemorrhage	Lovell (1973) Wilson and Poe (1973)

[1] Anorexia, reduced weight gain, and increased mortality are common vitamin deficiency signs and are not included in the table.

Table 4. – Vitamin requirement values reported for channel catfish [1]. Expressed as either IU or mg.kg^{-1} diet.

Vitamin	Requirement	Reference
Vitamin A	1 000-2 000 IU	NRC (1993)
Vitamin D	500 IU	Lovell and Li (1978)
	1 000 IU	Andrews *et al.* (1980)
	250 IU	Brown (1988)
Vitamin E	25 mg	Murai and Andrews (1974)
	50 mg	Wilson *et al.* (1984)
Vitamin K	NR	Murai and Andrews (1977)
Thiamin	1 mg	Murai and Andrews (1978*a*)
Riboflavin	9 mg	Murai and Andrews (1978*b*)
Pyridoxine	3 mg	Andrews and Murai (1979)
Panthotenic	10 mg	Murai and Andrews (1979)
acid	15 mg	Wilson *et al.* (1983)
Niacin	14 mg	Andrews and Murai (1978)
Biotin	R	Robinson and Lovell (1978)
Folic acid	1.2 mg	Duncan *et al.* (1993)
Vitamin B-12	R	Limsuwan and Lovell (1981)
Choline	400 mg	Wilson and Poe (1988)
Vitamin C	60 mg	Lim and Lovell (1978)
	11 mg	El Naggar and Lovell (1991)

[1] R – required but no value determined; NR – no requirement detected.

vitamin in fish feeds. Nevertheless, approximately 50% of the supplemental ascorbic acid is destroyed during the manufacture of extruded channel catfish feeds (Lovell and Lim, 1978) and excess ascorbic acid is routinely added to commercial formulations to ensure that an adequate level of the vitamin is retained in the final product.

Various derivatives of ascorbic acid, which are more stable than the parent compound, have been shown to have antiscorbutic activity in channel catfish. These include: L-ascorbate-2-sulfate (Murai *et al.*, 1978; Brandt *et al.*, 1985; Wilson *et al.*, 1989), L-ascorbyl-2-monophosphate (Brandt *et al.*, 1985), and L-ascorbyl-2-polyphosphate (Wilson *et al.*, 1989). However, L-ascorbate-2-sulfate does not appear to be utilized as well as certain of the other more stable forms of ascorbic acid by channel catfish (El Naggar and Lovell, 1991). At the current time it is still more economical to overfortify channel catfish feeds with the ethylcellulose-coated ascorbic acid than to use any of the other more stable forms of vitamin C.

Minerals

Fish utilize inorganic elements to maintain their osmotic balance between body fluids and the water. Some minerals in the water appear to be absorbed by the fish. For example, channel catfish can usually absorb sufficient calcium from the water to meet their requirement (Robinson *et al.*, 1986). However, calcium deficiency has been induced when channel catfish were reared in calcium-free water (Robinson *et al.*, 1986). The deficiency was characterized by a reduction in growth rate and in bone ash and a dietary calcium requirement of 0.45% was determined under these unusual conditions. Wilson and El Naggar (1992) were unable to obtain a dose-response relationship between dietary potassium level and whole body potassium concentration in channel catfish, indicating that these fish do not have a dietary requirement for potassium

Table 5. – Mineral deficiency signs and minimum levels of minerals required to prevent deficiency signs in channel catfish.

Mineral	Requirement	Deficiency signs [1]	Reference
Calcium	BLD [2]		
	0.45% [3]	Reduced bone ash	Robinson *et al.* (1986)
Phosphorus	0.45% [4]	Reduced bone mineralization	Andrews *et al.* (1973)
			Lovell (1978)
			Wilson *et al.* (1982)
Magnesium	0.04%	Muscle flaccidity, sluggishness, reduced bone, serum, and whole body magnesium	Gatlin *et al.* (1982)
Sodium	BLD		Wilson and El Naggar (1992)
Potassium	0.26%	None detected	Wilson and El Naggar (1992)
Chloride	BLD		Wilson and El Naggar (1992)
Zinc	20.00 mg.kg^{-1}	Reduced serum zinc and serum alkaline phosphatase activity, reduced bone zinc and calcium	Gatlin and Wilson (1983)
Selenium	0.25 mg.kg^{-1}	Reduced liver and plasma selenium-dependent glutathione peroxidase activity	Gatlin and Wilson (1984*b*)
Manganese	≤2.40 mg.kg ^{1}	None detected	Gatlin and Wilson (1984*c*)
Iron	30.00 mg.kg^{-1}	Reduced hemoglobin, hematocrit, erythrocyte count, reduced serum iron and transferrin saturation levels	Gatlin and Wilson (1986*a*)
Copper	5.00 mg.kg^{-1}	Reduced hepatic copper-zinc superoxide dismutase, reduced heart cytochrome c oxidase activity	Gatlin and Wilson (1986*b*)

[1] Anorexia, poor weight gain, and increased mortality are common deficiency signs for most mineral deficiencies.
[2] Below level of detection under normal rearing conditions.
[3] Determined in calcium-free rearing water.
[4] Expressed as available phosphorus.
[5] 150 mg zinc.kg^{-1} diet is recommended for practical feeds containing phytic acid (Gatlin and Wilson, 1984*a*).

with potassium in the rearing water at a concentration of 4 $mg.l^{-1}$ or higher. However, when these data were used to calculate the whole body potassium balance for each group of fish, it became clear that the fish do have a potassium requirement that can be met by either dietary potassium or the uptake of potassium from the rearing water.

The dietary requirements of several minerals have been determined for the channel catfish and the results are summarized in *table* 5. These requirement values were determined by feeding purified diets limiting in the mineral under study and evaluating various growth parameters and either tissue mineral levels or enzyme activities.

Mineral supplementation is generally added to practical channel catfish feeds. Natural feedstuffs are considered to be adequate in magnesium, sodium, potassium and chloride. Calcium and phosphorus are normally added as dicalcium phosphate mainly as a source of available phosphorus. Selenium is normally supplemented in the vitamin premix at a level to provide 0.1 $mg.kg^{-1}$ of feed. A trace mineral premix should be used which provides the following minerals in the feed ($mg.kg^{-1}$): manganese, 25; iodine, 2.4; copper, 5; zinc, 200; iron, 30; and cobalt, 0.05.

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