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TILAPIA: Environmental Biology and Nutritional Requirements

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TILAPIA: Environmental Biology and Nutritional Requirements

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Tilapia is one of the most widely cultured fish in the world. Currently, farmed tilapia represents more than 75% of world tilapia production (FAO, 2009), and this contribution has been exponentially growing in recent years. Several factors have contributed to the rapid global growth of tilapia. Tilapia are easily cultured and highly adaptable to a wide range of environmental conditions. Tilapia feed on a wide variety of dietary sources, including phytoplankton, periphyton, zooplanktons, larval fish, and detritus. Adult tilapia are principally herbivorous but readily adapt to complete commercial diets based on plant and animal protein sources. In the United States, the most commonly farmed tilapia species are, in order, Nile (*Oreochromis niloticus*), Mozambique (*O. mossambicus*), blue (*O. aureus*), and hybrids (Green, 2006). This publication provides a brief overview of environmental and nutritional requirements of tilapia.

ENVIRONMENTAL REQUIREMENTS

Tilapia can tolerate a wider range of environmental conditions—including factors such as salinity, dissolved oxygen, temperature, pH, and ammonia levels (table 1)—than most cultured freshwater fishes can. In general, most tilapia are highly tolerant of saline waters, although salinity tolerance differs among species. Nile tilapia is thought to be the least adaptable to marked changes (direct transfer, 18 parts per thousand in salinity); Mozambique, blue, and redbelly (*T. zilli*) are the most salt tolerant (El-Sayed 2006). With the exception of Nile tilapia, other tilapia species can grow and reproduce at salinity concentrations of up to 36 parts per thousand, but optimal performance measures (reproduction and growth) are attained at salinities up to 19 parts per thousand (El-Sayed 2006). Tilapia are, in general, highly tolerant of low dissolved oxygen concentration, even down to 0.1 mg/L (Magid and Babiker, 1975), but optimum growth is obtained at concentrations greater than 3 mg/L (Ross, 2000). Temperature is a major metabolic modifier in these fish. Optimal growing temperatures are typically between 22° C (72° F) and 29° C (84° F); spawning normally occurs at temperatures greater than 22° C (72° F). Most tilapia species are unable to survive at temperatures below 10° C (50° F), and growth is poor below 20° C (68° F). Blue tilapia are the most cold tolerant, surviving at temperatures as low as 8° C (46° F), while other species can tolerate temperatures as high as 42° C (108° F; (Sarig, 1969; Morgan, 1972; Caulton, 1982; Mires, 1995).

Other water quality characteristics relevant to tilapia culture are pH and ammonia. In general, tilapia can tolerate

Table 1. Limits and optima of water quality parameters for tilapia.

Parameter	Range	Optimum for growth	Reference
Salinity, parts per thousand	Up to 36	Up 19	El-Sayed (2006)
Dissolved oxygen, mg/L	Down to 0.1	> 3	Magid and Babiker (1975); Ross (2000)
Temperature, C°	8–42	22–29	Sarig (1969); Morgan (1972); Mires (1995)
pH	3.7–11	7–9	Ross (2000)
Ammonia, mg/L	Up to 7.1	< 0.05	El-Shafey(1998); Redner and Stickney, (1979)

a pH range of 3.7 to 11, but best growth rates are achieved between pH 7 to 9 (Ross, 2000). Ammonia is toxic to tilapia at concentrations of 2.5 and 7.1 mg/L as unionized ammonia, respectively, for blue and Nile tilapia (Redner and Stickney, 1979; El-Sherif et al., 2008) and depresses feed intake and growth at concentrations as low as 0.1 mg/L (El-Sherif et al., 2008). Optimum concentrations are estimated to be below 0.05 mg/L (El-Sherif et al., 2008).

NUTRITIONAL REQUIREMENTS

The low trophic level and the omnivorous food habits of tilapia make them a relatively inexpensive fish to feed, unlike other finfish, such as salmon, which rely on high-protein and lipid diets based on more expensive protein sources like fish meal. In addition, tilapia are similar to channel catfish (*Ictalurus punctatus*), in that they can tolerate higher dietary fiber and carbohydrate concentrations than most other cultured fish. To ensure high yield and fast growth at least cost, a well-balanced prepared feed is essential to successful tilapia culture. Slight variations exist among tilapia species, but nutrient requirements are primarily affected by the size of the fish.

Protein

Fish do not have a specific requirement for crude protein (CP) per se, but rather they need a combination of essential amino acids. Therefore, the profile of dietary protein is important when formulating diets for tilapia. Dietary proteins are used continuously by fish for maintenance, growth, and reproduction functions. When fed in excess, protein may be used as energy; however, the latter function is not desirable because of the expensive cost of proteins. The protein requirement of tilapia decreases with age and size (table 2), with higher dietary CP concentrations required for fry (30–56%) and juvenile (30–40%) tilapia but lower protein levels (28–30%) for larger tilapia (Winfree and Stickney, 1981; Jauncey, 1982; Al Hafedh, 1999; Siddiqui et al., 1988; Twibell and Brown, 1998). As with other warm-water fish, tilapia require 10 essential amino acids that need to be supplied by the diet (table 3). Essential amino acid requirements can be met by the use of a balance of both plant and animal proteins, and if necessary, by the inclusion of synthetic amino acids in the complete feed.

Table 2. Protein requirements (dry basis) of tilapia of various species and sizes.

Species	Size (g)	Requirement (% of diet)	Reference
O. niloticus	0.5-68.3	40	Al Hafid (1999)
	45.0–76.3	40	
	0.84–22.8	40	Siddiqui et al. (1988)
	40.4–108.0	30	
O. niloticus x *O. aureus*	21.3–81.5	28	Twibell and Brown (1998)
O. aureus	2.5–16.6	56	Winfree and Stickney (1981)
S. mossambicus	1.83–8.5	40	Jauncey (1981)

Lipids

Dietary lipids provide a major source of energy, facilitate the absorption of fat soluble vitamins, play an important role in membrane structure and function, serve as precursors for steroid hormones and prostaglandins, and serve as metabolizable sources of essential fatty acids. Winfree and Stickney (1981) found that for tilapia up to 2.5 g, the optimum dietary lipid concentration was 5.2%, decreasing to 4.4% for fish up to 7.5 g. Jauncey (2000) suggested that to maximize protein utilization, dietary fat concentration should be between 8 and 12% for tilapia up to 25 g, and 6 to 8% for larger fish. As with most fish, tilapia appear to have a requirement for n-6 (linoleic) fatty acids, and to a lesser extent, a requirement for n-3 (linolenic) fatty acids. Dietary lipids should supply at least 1% of n-6 fatty acids (Teshima et al., 1982). When dietary lipids contain con-

Table 3. Amino acid requirements (dry basis) of tilapia.*

Amino acid	% of dietary protein	
	O. niloticus[a]	*O. mossambicus*[b]
Arginine	4.20	2.82
Histidine	1.72	1.05
Isoleucine	3.11	2.01
Leucine	3.39	3.40
Lysine	5.12	3.78
Methionine[c]	2.68	0.99
Phenylalanine[d]	3.75	2.50
Threonine	3.75	2.93
Tryptophan	1.00	0.43
Valine	2.80	2.20

[a] Santiago and Lovell (1988). Requirements estimated by the dose-response method. Initial weight (13 to 87 mg) and final weight (103 to170 g).
[b] Jauncey et al. (1983). Requirements estimated by the whole body and muscle amino acid composition method.
[c] Cystine 0.54% of dietary protein.
[d] Tyrosine 1.79% of dietary protein.
* Note that the methionine requirement depends on dietary cystine concentration. If cystine is not included in the diet, part of methionine would be used to synthesize cystine and if cystine is supplied by the diet, the requirement of methionine is reduced. Likewise, tyrosine can be synthesized from phenylalanine and its supply by the diet would decrease the dietary requirement of phenylalanine for maximal growth.

siderable amount of polyunsaturated fatty acids, attention should be given to prevent oxidation of the dietary lipids. The resulting products of lipid oxidation are toxic, reduce the availability of other nutrients, and impact the quality of fish-flesh products.

Carbohydrates

Fish do not have a specific requirement for carbohydrates, because amino acid and fatty acid precursors can supply the required glucose via gluconeogenesis. This does not imply that carbohydrates should not be included in tilapia diets, however. Carbohydrates provide a relatively inexpensive source of energy compared to protein, and their inclusion can improve the quality of pelleted feeds. Tilapia can effectively utilize carbohydrate levels up to 30 to 40% in the diet, which is considerably more than most cultured fish (Anderson et al., 1984; Teshima et al., 1985). Fiber is usually considered indigestible, as tilapia do not possess the required enzymes for fiber digestion (although some cellulase activity from microbes has been found in the gut of *O. mossambica*) (Saha et al., 2006). For this reason, and to attain maximum growth, crude fiber levels in tilapia diets should probably not exceed 5% (Anderson et al., 1984).

The relationship between concentrations of dietary protein and energy is important in fish nutrition. Diets should be balanced to maximize the use of protein for growth by providing optimal amounts of energy as carbohydrates and lipids. The ratio of protein to energy (P:E; mg/Kcal) varies with fish age and size. For tilapia the optimum ratio for growth varies between 68 and 125, depending on species and size (Winfree and Stickney, 1981; Shiau and Huang, 1990).

Vitamins and Minerals

Vitamins and minerals are essential for normal fish metabolism. Vitamin and mineral supplementation in the form of premixes may be beneficial in intensive systems, although most of these requirements are usually met naturally in extensive and semi-intensive pond cultures. However, specific requirements are not exactly known for all vitamins. Table 4 gives ranges of vitamin requirements that have been determined for different tilapia species and hybrids. Because of the limited knowledge and the uncertainty regarding vitamin requirements, it is difficult to make general recommendations as to what the optimal concentrations should be, but general minimum levels are commonly applied to feeds. General mineral requirements for various tilapia species are presented in table 5. Basic knowledge of mineral toxicity and interactions among minerals is necessary when supplementation is made. Though not specific to tilapia, excessive supplies of certain minerals can cause deficiencies of others and in extreme cases toxicity to fish. For example, high dietary calcium can cause deficiencies in phosphorus, zinc, iron, and manganese. On the other hand, it has been shown that zinc, copper, and selenium, at high concentrations, can be toxic to various finfish species.

CONCLUSION

Although tilapia is one of the most studied cultured fish, specific dietary requirements are still lacking and the interaction among nutrients and with culture conditions are not completely understood. In addition, nutrient requirements may vary among tilapia species. Thus, readers are reminded that this publication is only a brief introduction to tilapia requirements, most of which were derived under controlled environmental conditions. More detailed information can be found in the additional references listed below.

Table 4. Vitamin requirements (dry basis) of tilapia of various species and sizes.

Vitamin/Species	Size (g)	Requirement (mg/kg of diet)	Reference
Vitamin B_1 (thiamine)			
O. niloticus	–	4	Lim et al. (2000)
O. mossambicus × *O. urolepsis honorum*	–	2.5	Lim and Leamaster (1991)
Vitamin B_2 (riboflavin)			
O. mossambicus × *O. niloticus*	1.46–42.0	5	Lim et al. (1993)
O. aureus	0.71–31.6	6	Soliman and Wilson (1992a)
Vitamin B_6 (pyridoxine)			
O. niloticus × *O. aureus*	0.73–2.7	1.7–9.5[a]	Shiau and Hsieh (1997)
	0.73–3.4	15.0–16.5[b]	Shiau and Hsieh (1997)
Pantothenic acid			
O. aureus	–	6	Roem et al. (1991)
	0.71–17.4	10	Soliman and Wilson (1992b)
Nicotinic acid (niacin)			
O. niloticus × *O. aureus*	2.2–28.8	26–121[c]	Shiau and Suen (1992)
Biotin			
O. niloticus × *O. aureus*	0.98–5.0	0.06	Shiau and Chin (1999)
Folic acid			
O. niloticus × *O. aureus*	0.41–4.1	0.82	Shiau and Huang (2001)
Vitamin B_{12} (cyanocobalamin)			
O. niloticus × *O. aureus*	1.0–47.7	NR	Shiau and Lung (1993)
Inositol (Myo-inositol)			
O. niloticus × *O. aureus*	0.51–4.8	400	Shiau and Su (2005)
Choline			
O. aureus	2.0–21.9	NR	Roem et al. (1990a)
O. niloticus × *O. aureus*	0.62–6.1	1000	Shiau and Lo (2000)
Vitamin C (ascorbic acid)			
O. niloticus	0.56–4.5	50	Abdelghany (1996)
	1.0–18.0	420	Soliman et al. (1994)
Vitamn A (retinol), IU/kg			
O. niloticus	11.4–33.1	5000	Saleh et al. (1995)
O. niloticus × *O. aureus*	1.6–9.3	5850–6970[d]	Hu et al. (2006)
Vitamin D (cholecalciferol)			
O. aureus	2.3–42.0	NR	O'Connell and Gatlin (1994)
O. niloticus × *O. aureus*	0.79–27.7	375	Shiau and Huang (1993)
Vitamin E (tocopherol)			
O. niloticus	0.49–7.8	10[f]	Satoh et al. (1987)
O. aureus	2–19.7	10–25[e]	Roem et al. (1990b)

[a] 28% protein diet, [b] 32% protein diet, [c] fed either glucose or dextrin diets, [d] depending on weight gain of fish, [e] fed either 3 or 6% lipid diet, [f] fed a 5% lipid diet.
* NR: not required.

Table 5. Mineral requirements (dry basis) of tilapia of various species and sizes.

Mineral/Species	Size (g)	Requirement	Reference
Major (g/kg of diet)			
Calcium			
O. aureus	2.3–61.3	7–7.5	Robinson et al. (1987); O'Connell and Gatlin (1994)
Phosphorus			
O. niloticus	6.1–32.0	< 9	Watanabe et al. (1980)
O. aureus	–	10	Viola et al. (1986)
Potassium			
O. niloticus × *O. aureus*	0.77–3.5	2–3	Shiau and Hsieh (2001)
Magnesium			
O. niloticus	20.0–54.4	0.59	Dabrowska et al. (1989)
O. aureus	0.5–9.0	0.5	Reigh et al. (1991)
Trace (mg/kg of diet)			
Zinc			
O. niloticus	3.1–22.1	20	McClain and Gatlin (1988)
O. aureus	8.5–23.1	30	Eid and Ghoneim (1994)
Chromium			
O. niloticus × *O. aureus*	1.23–13.1	2	Shiau and Lin (1993)
	0.55–4.0	140	Shiau and Shy (1998)

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