Eel, *Anguilla* spp.

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Introduction

Eel is one of the major aquaculture species, and its global production was estimated to have reached above 200,000 t in 1997. The four major cultivated species are *Anguilla japonica* in the Far East, *Anguilla anguilla* in Europe, *Anguilla rostrata* in North America and *Anguilla australis* in Australia and New Zealand. Among these, *A. japonica* is the dominant species and is cultivated mainly in China and Japan.

Arai (1991) reviewed the nutritional requirement of eels. Since then, some new information has arisen. This chapter attempts to collate the recent research and to cover fundamental aspects of eel nutrition.

Nutritional Requirements

Protein and amino acids

Eels are carnivorous and require a higher amount of protein than their herbivorous and omnivorous counterparts. Nose and Arai (1972) reported that young *A. japonica* require more than 45% dietary protein when a purified casein-based diet was used. Recently, Tibbets *et al.* (2000) estimated that the optimum level of dietary protein for juvenile American eel (*A. rostrata*) was 47% when the diet was herring meal-based. De la Higuera *et al.* (1989) reported that the optimal daily protein intake for maximum growth was about 1.4 g 100 g^{-1} fish for *A. anguilla*. This value is much higher than that for rainbow trout (*Oncorhynchus mykiss*) and common carp (*Cyprinus carpio*), which was reported to be 1.16 g 100 g^{-1} fish by Ogino (1980). The protein requirement of eel (45–47%) is relatively higher than that of other fish species.

Arai *et al.* (1972b) determined the qualitative amino acid requirements of *A. japonica* and *A. anguilla*, using a diet deficient in specific amino acids. When the eels were deprived of dietary arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine, respectively, they showed lower growth than fish on the control diet (bovine liver profile), which contained all these amino acids (Fig. 22.1). A recovery in growth was noted when the amino acid-deficient diets were replaced by the control diet. Thus, eels require the ten essential amino acids, as with other fish species.

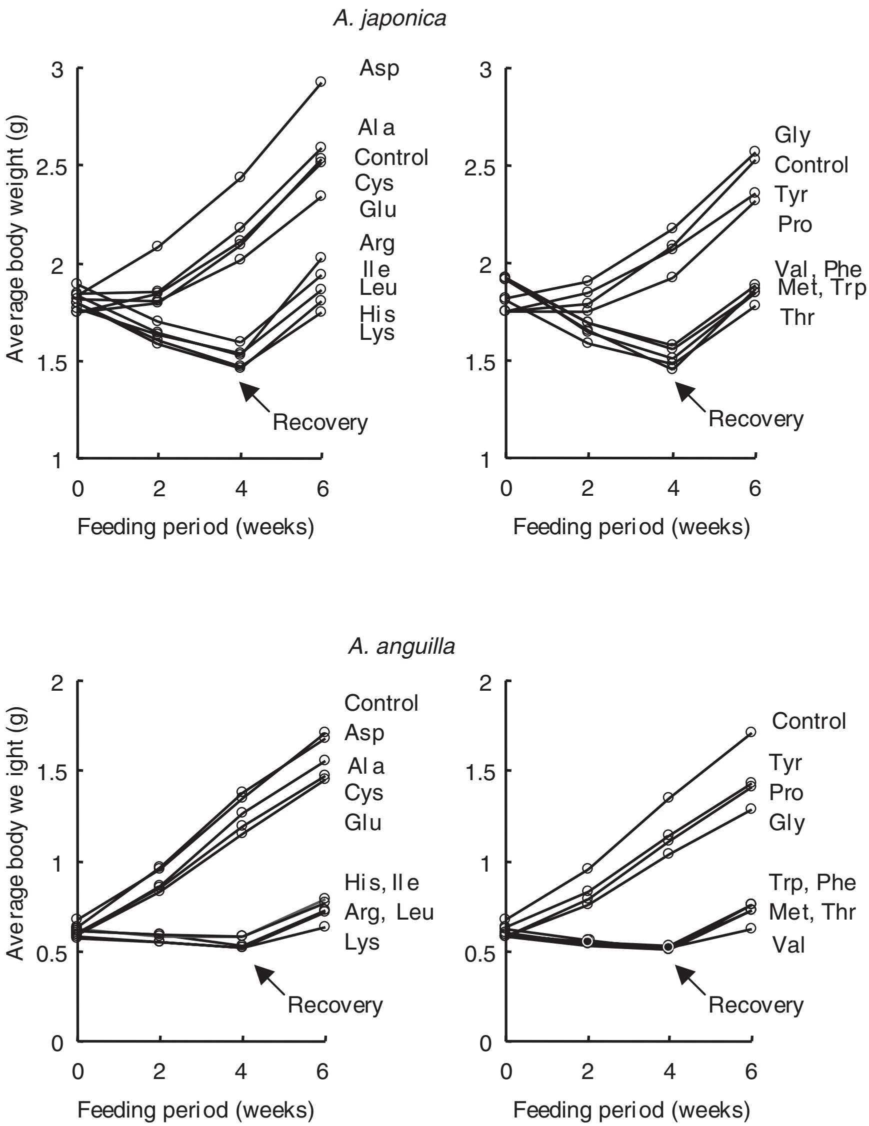

Fig. 22.1. Growth of eel (*A. japonica* and *A. anguilla*) fed amino acid-deficient (–○–) and complete (–●–) diets. Diets deficient in: Ala, alanine; Arg, arginine; Asp, aspartic acid; Cys, cystine; Glu, glutamine; Gly, glycine; His, histidine; Ile, isoleucine; Leu, leucine; Lys, lysine; Met, methionine; Phe, phenylalanine; Pro, proline; Thr, threonine; Trp, tryptophan; Tyr, tyrosine; Val, valine.

Nose (1979) carried out growth studies to determine the quantitative requirement of Japanese eel for each essential amino acid (Table 22.1). The arginine requirement of eel was lower than that of chinook salmon (*Oncorhynchus tshawytscha*). However, isoleucine and leucine requirements were higher than those of carp, channel catfish (*Ictalurus punctatus*) and Nile tilapia (*Oreochromis niloticus*). Further, the requirement of tryptophan was higher than that of the other species except tilapia. Recently, Akiyama *et al.* (1997) compared the essential amino acid requirements with the ratio of each essential amino acid content per total essential acid content (A/E ratio) among fish species, and inferred that Japanese eel was similar to milkfish (*Chanos chanos*) on the basis of its dietary requirements, while it ranked close to Nile tilapia in body amino acid profiles.

High-quality fish-meal has traditionally been a major ingredient in eel diets because of growth and palatability, averaging about 75% of the diet content (Gallagher and Degani, 1988). Among alternative protein sources, it was found that raw chicken meat was better than chicken blood in diets for European eel, and it was suggested that chicken meal and raw chicken wastes could be utilized in eel diets (Degani *et al.*, 1984). Recently, Lee and Bai (1997) reported that fish-meal can be replaced by haemoglobin powder up to 50% without supplementation of the three essential amino acids methionine, isoleucine and arginine for Japanese eel.

Schmitz *et al.* (1984) examined the digestibility of protein in the ingredients casein, gelatin, fish-meal, bacteria protein, soybean meal and soy-protein concentrate and reported values are 99, 94, 94, 89, 96 and 94%, respectively.

Lipids and fatty acids

Eel requires essential fatty acids, similarly to rainbow trout and common carp. Arai *et al.* (1971) examined the effects of supplemental lipids on the growth of

Table 22.1. Amino acid requirement of juvenile Japanese eel (from Nose, 1979).

Amino acid	Requirement as percentage of dietary protein*	Requirement as percentage of dry diet
Arginine	4.5	1.7
Histidine	2.1	0.8
Isoleucine	4.0	1.5
Leucine	5.3	2.0
Lysine	5.3	2.0
Methionine	3.2	1.2
Phenylalanine	5.8	2.2
Threonine	4.0	1.5
Tryptophan	1.1	0.4
Valine	4.0	1.5

* The experimental diet contained 38% crude protein.

young Japanese eel using purified casein-gelatin diets, and found that a mixture of maize oil and cod-liver oil at a 2 : 1 ratio was the most favourable for the growth of eel. Later Takeuchi *et al.* (1980) determined the essential fatty acid requirements of Japanese eel using diets containing methyl esters of fatty acids. They reported that the eel required both linoleic acid (18:2n-6) and linolenic acid (18:3n-3) in the same proportion as common carp but at a lower level in the diet – 0.5% rather than 1% of each.

Lipids play an important role as a source of energy in fish diets, especially for carnivorous species like eel, which utilize carbohydrates poorly as an energy source. Addition of lipids to a diet improved the utilization of dietary protein (protein-sparing effect). Burgos *et al.* (1989) studied the influence of partial replacement of protein content of diets by fat. They reported that decreasing dietary protein levels did not produce a decrease in body-weight gain, but instead body weight increased with increasing dietary fat level, indicating the possibility of limited protein replacement by fat. Degani *et al.* (1987) reported that large eels (40–120 g) grew well when fed diets containing a protein-to-energy ratio above 16.7 g MJ^{-1}. Gallego *et al.* (1993) also investigated the sparing effect of lipids on protein utilization. They obtained the best performance when fish were fed a diet containing 30% protein and 20% lipid, namely a protein/energy ratio of 16.1 g MJ^{-1} gross energy and a total energy content of 19.0 MJ kg^{-1} diet. Tibbets *et al.* (2000) estimated that the optimum protein/energy ratio for American eel was 22 g MJ^{-1}.

Fish-oil is the main lipid source in eel diet. Its superiority has been proved in a study by Gallagher and Degani (1988). They evaluated poultry meal and poultry oil as replacements for fish-meal and/or fish-oil in the diet of juvenile eels, and found that those fed the diet supplemented with 10% fish-oil had a significantly higher weight gain than those receiving either 5% fish-oil or 5 or 10% poultry oil.

Carbohydrates

As mentioned earlier, eels are carnivorous and therefore have limited ability to utilize dietary carbohydrates. Though supporting information is scanty, it has also been reported that the digestibility of gelatinized starch was quite high, ranging from 78 to 98%, when it was included in the diet at 20–60%. Gelatinized starch serves an important role as a binder for eel diet. It is an indispensable ingredient, irrespective of its doubtful utilization rate by eels.

Degani (1987) determined the influence of several dietary carbohydrate sources on enzyme activity and glucose content in the muscle and liver of eel. They reported that eels fed 30% bread flour or soluble maize starch had a higher glucose content in muscle and liver, and that aldolase activity was high in the fish on wheat meal, bread flour or soluble starch. Garcia-Gallego *et al.* (1991) evaluated the possibility of including high carbohydrate levels in commercial diets for eel, and suggested that the better utilization rates permit its inclusion at levels of 40% and above.

Vitamins

Arai *et al.* (1972a) reported the qualitative requirements of young *A. japonica* for water-soluble vitamins and listed their deficiency symptoms (Table 22.2). Japanese eel requires 11 water-soluble vitamins; however, deficiency was not evident in eels on a diet without *p*-aminobenzoic acid. Among the vitamins, deficiency of pyridoxine, pantothenic acid and choline produced effects earlier than the others, an indication of their relative importance. Most of the deficiency signs disappeared soon after feeding the related vitamin.

Yamakawa *et al.* (1975) described the signs of vitamin E deficiency and quantified the requirement of α-tocopherol using vitamin-free casein as the main protein source and fatty acid methyl esters as lipid sources. Deficiency signs observed were poor appetite and growth, haemorrhage and congestion in the fins and dermatitis on the skin. They estimated that the minimal requirement of α-tocopherol for growth of young eels was 200 mg kg^{-1} diet.

Minerals

Nose and Arai (1979) determined the mineral requirement of Japanese eel employing purified diets. Eels fed calcium or phosphorus-deficient diets gradually lost their appetite after a week of feeding, followed by reduced growth. However, when fed magnesium- or iron-deficient diets they showed poor appetite after 3–4 weeks. Eels fed the iron-deficient diet had hypochromic microcytic anaemia. The optimum requirements for calcium, magnesium, phosphorus and iron of young

Table 22.2. Vitamin deficiency signs in eels (from Arai *et al.*, 1972a).

Vitamin	Deficiency signs
Thiamine	Trunk-winding, ataxia, haemorrhage and congestion in fins, dark coloration and sluggish movement
Riboflavin	Haemorrhage and congestion in fins, dermatitis, photophobia and sluggish movement
Pyridoxine	Nervous disorders, epileptiform fits and convulsions
Pantothenic acid	Abnormal swimming, ataxia, mortality, haemorrhage in epidermis and dermatitis
Niacin	Abnormal swimming, ataxia, anaemia, haemorrhage in epidermis and dermatitis
Biotin	Abnormal swimming and dark coloration
Folic acid	Dark coloration and poor growth
Cyanocobalamin	Poor growth
Choline	White-grey intestine
Inositol	White-grey intestine
Ascorbic acid	Haemorrhage in fins, head and skin, and lower jaw erosion
p-Aminobenzoic acid	None
α-Tocopherol	Haemorrhage in fins and skin and dermatitis

Table 22.3. Proximate composition (%) of a typical commercial feed for eel (from Tsuda, 1997).

Type of feed	Eel size (g)		Moisture	Protein	Lipid
Paste type	Elver (just after catch)	0.2–0.5	82	14	0.8
Type A	Elver	0.4–1.0	7	65	5
	Elver	0.5–10	7	54	5
Type B	Elver	10–20	7	52	6
	Juvenile to growing	20–200	7	49	5
Extruded floating	Growing	10–200	7	49	16

eel were estimated to be about 2700, 400, 2500–3200 and 170 mg kg^{-1} diet, respectively.

Park and Shimizu (1989a,b) reported that optimal supplemental levels of aluminium and zinc to pollock meal-based diets were 15 and 50–100 mg kg^{-1} diet, respectively.

Practical Diets

Commercial diets for eel in Japan – dough-type feeds (A and B) – were developed almost 35 years ago. Recent innovations have been a paste-type diet developed to replace the *Tubifex* worm (*Tubifex hattai*) and a floating diet employed as a substitute for the dough-type diet. The paste-type diet is a weaning diet and includes fish flesh to improve its palatability for elvers; it is provided in a frozen condition. The paste diet is replaced by dough-type A diet, which contains wheat gluten as a binder. Dough-type B is the main diet for eel culture, and is used during the whole cultivation period after complete acclimatization to an artificial diet. Type B diet contains gelatinized starch as a binder. Table 22.3 provides the proximate composition of representative commercial diets for eel in Japan. The B-type commercial diet contains 5–6% lipid, which is derived from fish-meal. Since lipid is an important source of energy, besides its protein-sparing effect, it would be beneficial and effective to increase dietary lipid in the dough-type diet (B). It has been reported that the best growth and feed efficiency were obtained by increasing dietary oil to 15% (Tsuda, 1997).

Although a dry-type floating diet has been developed for eel, it has not gained wide market acceptance due to the slow growth of eel. The dough-type diet is still the dominant diet, although it is difficult and laborious to prepare. There is still a great need to develop a high-performance dry diet for eel.

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