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AMINO ACID NUTRITION OF FISHES: REQUIREMENTS AND SUPPLEMENTATION OF DIETS

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The purpose of this paper is: (1) to make a concise review of the published dietary requirements of fishes for amino acids, (2) to describe recent findings at the Tunison Laboratory concerning amino acid nutrition of trout, (3) to review specific signs of deficiency of amino acids, and (4) to discuss use of the fish egg amino acid pattern as a guideline to formulating new feeds or studying amino acid requirements of fishes for which there is limited information on their quantitative requirements.

All fish apparently require the same ten indispensable or essential dietary amino acids required by most other animals. These amino acids are: arginine (arg), histidine (his), isoleucine (ile), leucine (leu), lysine (lys), methionine (met), phenylalanine (phe), threonine (thr), tryptophan (trp) and valine (val). Cystine spares part of the methionine requirement in rainbow trout (Page, 1978). Although not proved, tyrosine may spare phenylalanine in fish diets. Published qualitative and quantitative requirements for amino acids by rainbow trout, various salmon, catfish, eel, sole and plaice are summarized in Table 1. For the sake of uniformity the quantitative requirements are expressed as percent of the protein because the total protein and the amino acids required in fish diets vary with species, age of fish, and energy content of diet. Between-species variations for the reported requirements for individual amino acids range from as low as 33% (for valine) to as high as 175% (for tryptophan). Many of the values in this table represent the results of only one experiment. Therefore, further repetitions and verifications with improved diets and experiments are desirable.

Recent studies by Ketola (unpublished) give quantitative data on the dietary requirements of rainbow and lake trout for lysine and arginine. Results of the study on rainbow trout (*Salmo gairdneri*) show (Table 2) that trout fed diets containing corn gluten meal without amino acid supplements gained only about 6% as much weight as did control fish fed herring meal. In addition, these trout fed the corn gluten meal diet had high mortality and developed caudal fin "rot." More than one-half of the tail fin was eroded. Supplementing the corn gluten meal diet with a mixture of essential amino acids, based on the composition of rainbow trout eggs (Table 3), markedly improved growth, fin condition, and survival to nearly equal that of the control trout fed herring meal. The mixture supplied seven essential amino acids, including lysine, arginine, tryptophan, histidine, isoleucine, valine and threonine. Lysine was the major component of the mixture essential for promoting growth, and it prevented fin rot and mortality. Results of feeding graded levels of lysine showed that the minimum requirement of rainbow trout for lysine for maximum growth was about 6.1% of the dietary protein, and lesser amounts for prevention of mortality and fin erosion. Supplemental arginine was needed for optimum growth. Feeding graded levels of arginine showed the minimum requirement of trout for arginine to be between 5.4 and 5.9% of the protein (data not shown). Supplemental tryptophan was not needed, even though corn gluten meal contains only about 0.5% of the protein as tryptophan. The fact that supplemental tryptophan was not needed confirms the report by Halver (1965) that indicated salmon require only about 0.5% of protein as tryptophan. A study of the lysine requirement of lake trout (*Salvelinus namaycush*) fed diets containing corn gluten meal with graded levels of lysine showed the minimum requirement for growth to be about 6% of the protein (Ketola, unpublished).

Signs of deficiency of dietary amino acids in fishes generally include reduced growth, poor feed conversion and reduced appetite. A few amino acid deficiencies lead to anatomical abnormalities. For instance, deficiency of methionine causes lake trout to develop bilateral lens cataracts and suffer poor growth and survival (Poston *et al.*, 1977). This effect of methionine deficiency on cataracts was confirmed in rainbow trout (Page, 1978; Page *et al.*, 1978). Tryptophan deficiency causes scoliosis and lordosis in sockeye salmon (Halver & Shanks, 1960) and rainbow trout (Shanks *et al.*, 1962; Kloppel & Post, 1975), but apparently not in the catfish (Wilson *et al.*, 1978). Further effects of tryptophan deficiency in rainbow trout include abnormal calcium deposits in the kidney and the bony plates surrounding the notochord and sheath (Kloppel & Post, 1975). Lysine deficiency in rainbow trout causes caudal fin rot, i.e. loss of much of the fin (Ketola, 1979a,b), but not in lake trout (Ketola, unpublished).

Studies conducted at the Tunison Laboratory demonstrate that fish egg amino acid pattern serves as a useful guide for formulating feeds and studying amino acid requirements for rainbow trout and Atlantic salmon. For instance, a study by Rumsey & Ketola (1975) showed the various approaches to appraising the deficient or limiting amino acids in commercial soybean meal (49% crude protein) as a sole source of protein in diets of rainbow trout. Table 3 shows the comparison of the amino acid composition (as percent of protein) in soybean meal (SBM) with that for the 1973 NRC chinook salmon requirements, the amino acid contents of whole trout carcass, the whole egg of rainbow trout and FPC (fish protein concen-

Table 1. Qualitative and quantitative requirements for amino acids by various fishes (Superscript numerals within table indicate references for specific amino acids)

Species of fish	Arg	His	Ile	Leu	Lys	Met & Cys	Phe & Tyr	Thr	Trp	Val	References*
					(R = required in diet. Values are expressed as percent of protein)						
Rainbow trout (*Salmo gairdneri*)	R[1,2]	R	R	R	R[1,2,3]	3.0[2,4,5]	R	R	R[6]	R	7
Chinook salmon (*Oncorhynchus tshawytscha*)	6.0[8]	1.75[8]†	2.25[9]‡	4.0[9]	5.0[10]	3.75[11]	5.25[9]	2.25[10,12]	0.4–0.6[13]	3.25[9]	14
	6.0	1.75	2.25	4.0	5.0	3.75	5.25	2.25	0.5	3.25	15
Coho salmon (*O. kisutch*)	6.0[8]†	1.75[8]	—	—	—	—	—	—	0.5–0.6[13]	—	
Sockeye salmon (*O. nerka*)	R	R	R	R	R	R	R	R	0.5–0.6[13]	R	16
Channel catfish§ (*Ictalurus punctatus*)	4.3[17]	1.5[18]	2.6[18]	3.5[18]	5.0[19] 6.2–7.3[20]	2.3[21]	4.5[22]	2.2[23]	0.5[23]	3.0[18]	24
Carp (*Cyprinus carpio*)	4.2–4.3	2.1	2.3–2.6	3.4–3.9	5.7	3.1	6.5	3.9	0.8	3.6	25–28
Japanese eel (*Anguilla japonica*)	3.9–4.5	1.9–2.1	3.6–4.0	4.1–5.3	4.8–5.3	4.5–5.0	5.8	3.6–4.0	1.0–1.1	3.6–4.0	25,28,29,30
European eel (*A. anguilla*)	R	R	R	R	R	R	R	R	R	R	30
Sole‖ (*Solea solea*)	R	R	R	R	R	R	R	R	—	R	31
Plaice‖ (*Pleuronectes platessa*)	R	R	R	R	R	R	R	R	—	R	31

* References: 1. Ketola (1979a,b), 2. Nose (1974), 3. Belik & Potmesil (1978), 4. Page (1978), 5. Page *et al.* (1978), 6. Kloppel & Post (1975), 7. Shanks *et al.* (1962), 8. Klein & Halver (1970), 9. Chance *et al.* (1964), 10. Halver *et al.* (1958), 11. Halver *et al.* (1959), 12. DeLong *et al.* (1962), 13. Halver (1965), 14. Halver *et al.* (1957), 15. NRC (1973), 16. Halver & Shanks (1960), 17. Robinson *et al.* (1980a), 18. Wilson *et al.* (1980), 19. Robinson *et al.* (1980b), 20. Wilson *et al.* (1977), 21. Harding *et al.* (1977), 22. Robinson *et al.* (1979), 23. Wilson *et al.* (1978), 24. DuPree & Halver (1970), 25. NRC (1977), 26. Nose *et al.* (1974), 27. Nose *et al.* (1978), 28. Cowey & Sargent (1979), 29. Nose (1969), 30. Arai *et al.* (1972), 31. Cowey *et al.* (1970).

† The data show that the requirement for optimum feed/gain may exceed that for growth that is shown in this table.

‡ The requirement for isoleucine increases as the level of leucine increases.

§ The values, 6.2–7.3% of protein, for the minimum requirement of catfish for lysine do not reflect the conclusions of Wilson *et al.* (1977) but rather the data that they present. Their data (Table 5) show that lysine at 5.2% of protein (or 1.25% of diet) was deficient because growth rate and serum free lysine were significantly depressed relative to values for higher levels of lysine.

‖ Requirements indicated by rates of *in vivo* incorporation of intraperitoneal injections of [U-^{14}C]glucose into amino acids.

Table 2. Growth of rainbow trout fed corn gluten meal diets with and without supplemental amino acids based on the composition of the trout egg

Diet (14 weeks)	Gain* (% of control)
Basal† 67% corn gluten meal	6A
+ Amino acid mix‡ (6.7)§	95BC
− val	91AC
− trp	99BC
− thr	101BC
− arg	63D
− lys (1.1)§	7A
+ lys (2.1)	17E
+ lys (3.1)	43F
+ lys (4.1)	57D
+ lys (5.1)	82G
+ lys (6.1)	100BC
Herring meal control	100BC

* The average initial body weight was 1.1 g/fish. Values not followed by the same letter are significantly different ($P < 0.05$).

† The basal diet contained 47% protein, 40.2% from corn gluten meal and the remainder from glutamic acid and glutamic acid hydrochloride included to maintain all diets isonitrogenous and isochloric.

‡ Amino acid supplements based on the amino acid composition of rainbow trout eggs. Mixture includes those shown in this table plus His and Ile.

§ Values in parentheses represent the amounts of lysine expressed in percent of protein.

trate). Based upon comparison with the NRC requirements for chinook salmon, commercial SBM appeared to be deficient in methionine alone. When compared with whole trout carcass, SBM was low in methionine, histidine, and lysine. When compared with whole egg of rainbow trout, SBM was low in lysine, methionine, leucine, valine and threonine. When compared with FPC, SBM was low in histidine, tryosine, tryptophan, in addition to those amino acids determined using the trout egg. Diets were formulated to quantitatively correct the apparent deficiencies in SBM by supplementing the respective amino acids in the meal up to the levels defined by the NRC, trout carcass, trout egg, or FPC. The results showed that the growth of fingerling rainbow trout fed diets containing 80% commercial dehulled solvent-extracted soybean meal (49% protein) as the sole source of protein was not significantly improved when supplemented with methionine to correct a possible deficiency in the meal based on the 1973 NRC amino acid requirements of the chinook salmon. Furthermore, growth was not significantly improved when the diet was supplemented with three amino acids based on the amino acid composition of whole trout carcasses. In contrast, growth was significantly increased by 43% when amino acid supplements were made to correct all (five) apparent shortages in soybean meal relative to the amino acid content in rainbow trout eggs. Additional amino acid supplementation based on FPC did not significantly further improve growth.

Table 3. Amino acid composition of soybean meal and a mixture of proteins compared with the NRC requirements of chinook salmon and various fish products (values are expressed as percent of protein)

Amino acid	SBM*	MIX†	FPC‡	Salmon§ NRC	Trout Carcass‖	Trout Egg¶	Atlantic salmon Carcass**	Atlantic salmon Egg††
Arg	7.6	7.2	6.3	6.0	5.9	5.7	5.9	6.4
His	2.4	2.4	2.1	1.8	3.1	2.5	3.3	2.7
Lys	6.4	6.3	8.8	5.0	8.0	7.3	8.6	8.8
Met	1.5	1.5	3.2		2.6	2.9	3.3	2.7
Met + Cys	3.1	3.1	3.6	4.0	3.3	3.9	3.9	4.5
Trp	1.3	1.3	1.0	0.5	·	1.0	--	1.1
Phe	5.4	5.3	4.6		4.0	5.5	4.5	5.3
Phe + Tyr	9.4	9.2	7.9	5.1	7.4	9.7	7.6	6.4
Leu	7.6	7.7	8.4	3.9	6.7	9.5	7.8	10.3
Ile	5.2	5.2	5.5	2.2	3.7	4.7	5.1	6.4
Val	5.4	5.4	6.3	3.2	4.2	6.2	5.6	7.9
Thr	4.0	4.1	4.1	2.2	3.3	4.8	3.9	5.9

* SBM = commercial soybean meal (49% protein).

† MIX = mixture of soybean meal, 62; dried whey, 5; alfalfa meal, 3; brewers dried yeast, 5; and corn distillers dried solubles, 5% of diet.

‡ FPC = fish (herring) protein concentrate, Prot-Animal, Astra Pharmaceutical Products, Inc., Boston, Mass. (Reference to trade name does not imply Government endorsement of commercial products.)

§ 1973 National Research Council, National Academy of Sciences: requirements of chinook salmon for amino acids. (Values converted to percent of protein.)

‖ Composite whole trout carcasses (*Salmo gairdneri*, *S. trutta* and *Salvelinus fontinalis*) (Rumsey & Ketola, 1975).

¶ Whole-egg protein from rainbow trout; values are averages for unfertilized and eyed eggs (Suyama & Ogino, 1958).

** Fingerlings, unpublished data from Tunison Laboratory of Fish Nutrition.

†† Ovarian tissue (Cowey *et al.*, 1962).

A feeding experiment was conducted with Atlantic salmon (*Salmo salar*), involving several modifications of the basal diet that contained 72% soybean meal (SBM) as the sole source of protein (38% of diet). The modifications of the basal diet included fortification with trace nutrients, glutamic acid and glutamic acid·HCl with and without the five supplemental crystalline amino acids determined to be effective for rainbow trout fed the basal SBM diet. In an attempt to further improve growth, the diet was also modified to contain a mixture (Table 3) of protein sources (62% SBM, 5% dried whey, 3% alfalfa meal, 5% brewers dried yeast, and 5% corn distillers dried solubles) or 10% brewers dried yeast or 10% herring fish meal, or to contain fish meal as the only source of protein in place of SBM. The mixture of protein sources had an amino acid composition similar to that of SBM alone. All diets were formulated to contain 38% protein and equal levels of total added amino acids and amino acid hydrochlorides by balancing with non-essential glutamic acid and glutamic acid hydrochloride. The results of feeding salmon these diets (Table 4) showed that growth and feed efficiency was significantly improved by supplementing with five amino acids, yeast, herring meal, or a mixture of protein sources. Supplementing the mixture of proteins with the five amino acids based upon the trout egg further improved ($P < 0.05$) feed efficiency and growth to about 82% of that for salmon fed all fish meal protein in their diets. The conclusion from this experiment was that growth of salmon fed diets with SBM could be markedly enhanced by replacing part of the meal with dried whey, alfalfa meal, brewer's dried yeast and corn distillers dried solubles even though the amino acid content was not markedly changed. Growth was significantly improved however, by the mixture of five amino acids determined for SBM alone using the trout egg as the criterion for supplementation.

Another study was conducted with Atlantic salmon fed the diet with the protein mixture containing mostly soybean meal with and without amino acid supplements based on the trout egg, Atlantic salmon egg or carcass composition as shown in Table 3. Results of feeding these diets (Table 5) showed that supplementing with the five amino acids (lys, met, leu, val, and thr) based on the rainbow trout egg criterion significantly improved growth and that further supplements based on the salmon egg and carcass composition gave no significantly further response.

The effects of separate additions of the five amino acids in the mixture based on the rainbow trout egg was investigated with Atlantic salmon fed diets containing the protein mixture containing mostly SBM. The results (Table 6) showed that supplements of single amino acids had no significant effect on growth. Based on the 1973 NRC requirements of chinook salmon this diet containing mainly SBM should be expected to be deficient in methionine alone but clearly was not. In contrast, adding the combination of five amino acids (based on the rainbow trout egg criterion) significantly improved growth to about 85% of that for salmon fed a commercially prepared closed formula diet designed for Atlantic salmon. These results suggest that two or more amino acids are co-limiting in this diet.

Another experiment was conducted with Atlantic salmon fry to investigate the influence of heat treatment of commercial SBM. Heat treatment was investigated because laboratory analyses showed that many samples of commercial soybean meals (49% protein) had dye binding values of 3.5–3.7 mg of cresol red per g of meal according to the method of Olomucki & Bornstein (1960). Such values indicated that some meals might be underheated. Commercial SBM having a dye binding value of 3.6 mg of cresol red per g of meal was investigated with and without being autoclaved to give dye binding values of 4.0 and 4.4 mg/g. These three meals were incorporated into diets with and without the mixture of five amino acids (based on the trout egg) added at the expense of gluta-

Table 4. Soybean meal and amino acids in diets of fingerling Atlantic salmon*

Diet, 8 weeks (% in diet)	Gain† (g/fish)	Feed/Gain (g/g)
Soybean meal‡ (72%)	0.7 A§	6.0 A§
+ 5 amino acids‖	3.0 BC	2.4 BC
+ brewers dried yeast¶ (10%)	2.4 D	2.8 B
+ herring meal¶ (10%)	3.3 B	2.1 CD
Mixture**	2.6 CD	2.7 B
+ 5 amino acids‖	3.6 B	1.9 D
Herring meal (49%)	4.4 E	1.6 D
Pooled SE	0.2	0.2

* Ketola, unpublished.

† Initial average body weight was 5 g/fish.

‡ Cresol red binding value was determined to be 3.5 mg/g of commercial soybean meal by the method of Olomucki & Bornstein (1960).

§ Values not followed by the same letter are significantly different ($P < 0.05$).

‖ Lysine, methionine, leucine, valine and threonine at levels equal to differences between trout egg and SBM in Table 3.

¶ Substitutions at the expense of soybean meal, dietary oil and dextrin in order to maintain all diets isonitrogenous and isoenergetic.

** See MIX, Table 3.†

Table 5. Effects of supplemental amino acids on Atlantic salmon fed diets containing mainly soybean meal and a mixture of proteins*

Diet (8 weeks)	Criterion†	Gain‡ (g/fish)
Basal§ (mainly soybean meal)		2.8 A‖
+ Leu, Lys, Met, Val, & Thr	Trout egg	3.8 B
+ His, Phe, & Cys	Salmon egg	3.9 B
+ Leu, Lys, Met, Val, & His	Salmon carcass	3.9 B
Pooled SE		0.15

* Ketola, unpublished.

† All amino acids were added at levels equal to the differences between the mixture (MIX) and the criterion designated in Table 3.

‡ Initial average body weight was 2.9 g/fish.

§ The diet contained the mixture of proteins (MIX) shown in Table 3†. Commercial soybean meal was determined to bind 3.6 mg of cresol red/g of meal.

‖ Values not followed by the same letter are significantly different ($P < 0.05$).

mic acid and glutamic acid hydrochloride to maintain all diets isonitrogenous and isochloric. Fry were fed these diets for 10 weeks. Results (data not shown) showed highly significant increases in growth due to autoclaving of SBM and supplementation with amino acids, but there was no significant ($P > 0.1$) interaction between autoclaving and supplementation. More specifically, commercial SBM without additional autoclaving (dye binding value, 3.6 mg/g) supported growth only 77–82% that of autoclaved meals. There was little or no difference in growth between fry fed autoclaved meals with dye binding values of 4.0 and 4.4 mg/g. The growth improvement (9–15%) with amino acid supplements was fairly consistent regardless of heat treatment of SBM. This experiment showed that commercial soybean meal having a dye binding value of 3.6 mg/g was underheated for young Atlantic salmon, and additional heating of SBM to give a dye binding value of about 4.0 mg/g supported maximum growth when supplemented with amino acids. Heat treatment of SBM in this range (dye binding values of 3.6–4.4 mg/g) had no apparent effect on the growth response to supplements of amino acids.

Table 6. Amino acid supplements of Atlantic salmon diets containing mainly soybean meal*

Diet (10 weeks)	Gain† (g/fish)
Basal‡ (mainly soybean meal)	12.0 A
+ Leu	12.2 A
+ Val	11.6 A
+ Thr	11.9 A
+ Met	12.3 A
+ Lys	11.4 A
+ All five§	14.2 B
Commercial Atlantic salmon diet	16.7 C
Pooled SE	0.3

* Ketola, unpublished.

† Initial average body weight was 6 g/fish. Values not followed by the same letter are significantly different ($P < 0.05$).

‡ See MIX, Table 3†. Cresol red dye binding value for soybean meal was 3.5 mg/g.

§ Amino acid supplements based on the composition of the rainbow trout egg.

Another experiment was conducted by feeding the protein mixture containing mostly SBM to rainbow trout. Results of feeding supplements of methionine alone were compared with those of feeding the five amino acids based on the content of trout eggs (Fordiani & Ketola, 1980). A special batch of soybean meal was obtained and fed either raw or after heat treatment and having cresol red dye binding values of 2.7 or 4.4 mg/g of meal, respectively, as determined by the method of Olomucki & Bornstein (1960). The results of this experiment (Table 7) showed that growth was markedly suppressed by feeding the raw meal. Adding methionine or the five amino acids tended ($P < 0.1$) to improve growth of trout fed raw SBM.

In contrast, when the heated meal was fed, growth was not improved by supplemental methionine but was significantly improved by the mixture of five amino acids. The diet with soybean meal properly heated and supplemented with amino acids supported excellent growth, almost 90% of that for the herring meal control diet.

These experiments with commercial soybean meal point to the limitations of extrapolating the amino acid requirements of the chinook salmon (NRC, 1973) to the formulation of practical diets for Atlantic salmon and rainbow trout. Furthermore, they demonstrate the potential of using the amino acid composition of fish eggs for approximating dietary needs of fish.

Another experiment was conducted with Atlantic salmon fry fed diets containing 40% casein as the source of protein along with other ingredients to provide the known nutrients. Amino acid supplements were made based on comparison of the amino acid contents of casein with the 1973 NRC requirements for chinook salmon, and with amino acid compositions of the Atlantic salmon egg and whole carcass and fish protein concentrate as shown in Table 3. All diets were maintained isonitrogenous and isochloric by additions of glutamic acid and glutamic acid hydrochloride. The results of feeding these diets for ten weeks (Table 8) show that salmon fed the basal diet

Table 7. Effect of amino acid supplements on rainbow trout fed diets containing raw or heated soybean meal*

Diet† (12 weeks)	Gain‡ (g/fish)
Soybean meal, raw§	0.9 A‡‡
+ Met‖	1.8 A
+ 5 amino acids¶	1.7 A
Soybean meal, heated**	6.8 B
+ Met	6.7 B
+ 5 amino acids	9.2 C
Herring meal††	10.5 D
Pooled SE	0.2

* Unpublished data of T. R. Fordiani & H. G. Ketola, Department of Poultry and Avian Sciences, Cornell University, Ithaca, N.Y. and Tunison Laboratory of Fish Nutrition, Cortland, N.Y. U.S.A.

† See MIX in Table 3†.

‡ Initial average body weight was 6.2 g/fish.

§ Cresol red dye binding value, 2.7 mg/g.

‖ Based on 1973 NRC requirements for chinook salmon.

¶ Based on composition of rainbow trout eggs: Leu, Lys, Met, Val & Thr.

** Autoclaved soybean meal; cresol red dye binding value, 4.4 mg/g.

†† Control diet.

‡‡ Values not followed by same letter are significantly different ($P < 0.05$). Single degree of freedom contrast shows that the gain for trout fed the unsupplemented raw soybean meal was significantly ($P < 0.1$) slower than those fed supplemented raw meal collectively.

grew slowly and had high mortality. Supplementing with amino acids based on the NRC requirements or salmon carcass did not significantly improve survival. In contrast, adding amino acids based on FPC significantly improved survival and supplements based on the salmon egg improved survival best of all. Growth rates tended to show parallel beneficial effects of amino acid supplements, however variability was high among the triplicate lots of fish having high mortality. Therefore even marked differences in growth were not statistically significant ($P > 0.05$). In spite of the lack of significant differences in growth rates, the amino acid supplements based on the composition of the salmon egg were obviously much more effective for improving survival than were supplements based on the NRC requirements or other criteria.

Table 8. Atlantic salmon fed diets containing casein with amino acid supplements based on various criteria*

Diet, 10 weeks (criteria)†	Gain‡ (g/fish)	Mortality (%)
Basal, 40% casein	2.4	60 A§
+ Amino acids‖ (NRC)	3.0	62 A
+ Amino acids¶ (Carcass)	3.1	64 A
+ Amino acids** (FPC)	3.4	31 B
+ Amino acids†† (Egg)	4.1	11 C
Pooled SE	0.5	8

* Ketola and Rumsey, unpublished.

† For criteria see Table 3.

‡ Initial average body weight was 2.9 g/fish.

§ Values not followed by the same letter are significantly different ($P < 0.05$).

‖ Arg·HCl, 1.1; Cys, 0.9; Phe, 0.1% of diet.

¶ Arg·HCl, 0.8; His·HCl, 0.1; Lys·HCl, 0.7; Met, 0.2; Cys, 0.2% of diet.

** Arg·HCl, 1.2; Lys·HCl, 0.8; Met, 0.1; Cys, 0.3; Thr, 0.2; Trp, 0.2% of diet.

†† Arg·HCl, 1.3; His·HCl, 0.04; Ile, 0.5; Leu, 0.6; Lys·HCl, 0.8; Cys, 0.1; Phe, 0.1; Thr, 0.1; Val, 0.1% of diet.

Although the amino acid contents of fish eggs appear to differ from the reported dietary requirements of the fish, the composition of the egg provided an effective guide for successful amino acid supplementation of proteins in fish feeds for Atlantic salmon and rainbow trout. Table 9 includes the amino acid compositions of eggs from various species of fishes for possible future use in formulating feeds or studying nutritional requirements. These composition data represent various species of fishes for which requirements for dietary amino acids are not well established, if at all. Some of these values are based on older methods of analysis and may need to be confirmed or updated. However, the effectiveness of using the fish egg amino acid profile in studies with rainbow trout and Atlantic salmon suggests a potential for using such composition data in studies on dietary amino acid requirements of other species of fishes.

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Table 9. Amino acid composition of eggs of various fishes (All values are expressed as percent of protein)

Species of fish	Arg	Cys	His	Ile	Leu	Lys	Met	Phe	Thr	Trp	Tyr	Val	Reference*
Rainbow trout	5.70	1.03	2.47	4.71	9.45	7.30	2.89	5.48	4.82	0.98	4.23	6.23	1†
(*Salmo gairdneri*)	7.6	—	2.8	4.7	7.6	8.3	2.1	5.2	6.0	—	—	8.9	2‡
Atlantic salmon (*Salmo salar*)	6.4	1.7	2.7	6.4	10.3	8.8	2.7	5.3	5.9	0.98	1.1	6.2	3§
Chinook salmon (*Oncorhynchus tschawytscha*)	7.7	—	2.6	6.8	9.4	8.8	3.0	4.8	5.8	0.9	—	7.0	4
Coho salmon (*O. kisutch*)	7.0	—	2.8	7.5	10.0	8.8	2.7	4.9	5.9	0.9	—	7.1	4
Sockeye salmon (*O. nerka*)	7.2	—	2.7	7.5	10.2	8.5	2.8	4.8	5.8	0.9	—	7.3	4
Pink salmon (*O. gorbuscha*)	7.23	—	2.85	6.94	9.44	8.86	3.04	4.87	5.14	1.10	—	8.12	4
Atlantic silversides (*Menidia menidia*)	6.5	0.5	4.7	5.0	7.7	7.9	3.9	3.6	5.2	—	4.6	7.2	5
Walleye (*Stizostedion vitreum*)	5.7	—	2.9	6.4	8.3	7.8	3.1	4.8	5.2	1.2	4.1	7.1	6
Catfish (*Ictalurus punctatus*)	5.4	—	2.2	5.1	9.7	7.7	3.4	3.9	6.0	—	3.9	5.9	7

* References: 1. Suyama & Ogino (1958), 2. Satia *et al.* (1974), 3. Cowey *et al.* (1962), 4. Seagran *et al.* (1954), 5. Schauer *et al.* (1979), 6. Nickum, J. G., Ketola, H. G. & Rumsey, G. L., unpublished, 7. Wilson, R.P., unpublished.

† Averages for eggs both eyed and unfertilized.

‡ Domesticated strain of rainbow trout at the University of Washington.

§ Calculated from values for the immature ovary from Table 3.

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