# AQUACULTURE NUTRITION AND AQUATIC FEED TECHNOLOGY

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## Introduction

Fish nutrition and feed technology is attempted to be presented to this international audience in a nutshell, in this write-up, to support the presentation and to serve as a ready reckoner. Fish nutrition needs to be understood from two angles. One is from the fundamental point of view and another is the application of this fundamental knowledge as technologies. The fundamental understanding is in terms of the nutrients which are universally present and applicable. The macronutrients classified as protein, lipid and carbohydrate determine the cost of the food because the quantity involved is usually high.

## Proteins

Proteins are the the most expensive nutrient in nature is made up of amino acids, which are grouped as essential and non-essential based on their requirement in food and feed. Essential amino acids are those required in food or feed because they cannot be synthesized by animals to meet the total nutritional requirement. Non-essential amino acids are the ones that can be synthesized according to their requirement within the body. Functionally proteins are required for growth which means that its requirement is higher in the early stages of growth and declines as growth progresses. Apart from this, there are a plethora of functions proteins impart. Immunity, structural integrity, biological catalysis (enzymes) endocrine functions etc., to name a few. This list can be populated.

## Lipids

Lipids are energy-rich nutrients and are made up of fatty acids. They are also classified similarly to amino acids as essential and non-essential. Essential fatty acid requirements need to be met through feed. In aquatic nutrition, the essentiality unlike terrestrial animals is for highly unsaturated fatty acids (HUFA) or polyunsaturated fatty acids (PUFA) which are characterized by carbon chains of more than 20 in number. The essential fatty acids essential in terrestrial animal nutrition, including humans, are linoleic and linolenic acid. They have less than 20 carbon atoms. The essential fatty acids for aquatic animals are eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA) and arachidonic acid (ARA) whose number of carbon atoms and position of double bonds are denoted as 20:5 (n-3), 22:6 (n-3), 20:4 (n-6) respectively, indicating the presence of more than 20 carbon atoms or more in them. Even though protein is also a source of energy in aquatic animals, they are not as storable as lipids. Moreover, lipids approximately contain 2.25 times more energy than proteins or carbohydrates. Other than that, lipids have more biological functions as metabolic regulators, viz., a structural component of membranes, storage and transport of metabolic fuel, protective coating on the surface of many organisms and cell surface components concerned with cell recognition.

**Carbohydrates**

Carbohydrates are the cheapest source of energy. There is no absolute requirement for this nutrient in aquatic organisms. This is because of synthesis of glucose from non-glucose precursors such as protein and lipid through gluconeogenesis is efficient in aquatic animals. Now it is well known that their level of inclusion is limited in aquatic feeds compared to feeds for terrestrial livestock like poultry. Its digestibility in fish and shrimp depends upon, sources, processing and level of inclusion. Evaluations focused on the maximum level of inclusion without physiological disorders, rather than defining an optimal level needed for growth. This, in turn, spares protein and lipid as sources of energy which is economically beneficial. The ability of fish to utilize carbohydrates varies among species. Making carbohydrates more bioavailable through gelatinization is now known to increase the efficiency of utilization of carbohydrates, especially starch in aquatic feeds. The digestibility of raw starch is lower (30 – 50%) than that of gelatinized starch (50 – 90%). Non-gelatinized starch has been demonstrated to function as an immunoprotectant compared to gelatinized starch in *Labeo rohita*. The earliest reports of the optimum level of inclusion of starch in salmonids were 12%. Now, the maximum inclusion levels fall between 15 – 25% in salmonids and marine fish, 20 – 45% in shrimp and 50% in omnivorous fish. Dietary fibre levels are not to exceed 10%.

**Vitamins**

These are micronutrients; classified as fat soluble and water soluble depending upon their solubility. Fat is storable; fat-soluble vitamins are also storable. Contrarily, water-soluble vitamins are not storable. Day-to-day requirements are met through food and excess, if any, is excreted. In aquatic animals, the occurrence of vitamin deficiencies is rare because, whenever the animals consume fat, fat-soluble vitamins A, D, E and K are also consumed and stored. Water soluble vitamins, mainly belonging to the B-complex group become available through microbial synthesis from the resident microbial population in water. The situation is so, that the likelihood of a vitamin deficiency is only for vitamin C (Ascorbic acid). Primates, guinea pigs, birds and many fishes cannot synthesize vitamin C from glucose because of the absence of the enzyme L-gluconolactone oxidase. Deficiencies due to vitamin C are (1) curvature of the spinal column is prominent. (2) Scoliosis – lateral curvature, lordosis – vertical curvature of the spine. (3) External and internal haemorrhages. (4) Erosion of fins and depigmented vertical bands around mid-section. (5) Distorted gill filament cartilage. (6) Reduced rate of wound healing. (7) Deformed head and gill opercula. (8) Black death in shrimp is characterized by melanized haemocyteic lesions distributed throughout the collagenous tissues. Forms of vitamin C are Ascorbyl monophosphate Ca (AAMP), and Ascorbyl polyphosphate (AAPP) Stay C. Retention of 90% in stored feeds and 85% in semi-moist feeds is achievable with these forms. Coated forms of Vitamin C were unstable (50% after extrusion). Vitamin C coated with cellulose derivatives, silicone-coated ascorbic acid and proteins are also available. (Ref: Gadient and Fenster, 1994, Aquaculture 124, 207-211)

**Mineral nutrition**

Out of the 90 naturally occurring inorganic elements, 29 are considered essential in all animals including fish. The dietary requirement of macro-minerals established in fish is for Ca, P, Mg, Chloride, Na and K and the micro-mineral requirement of Cu, Co, Cr, Fe, I, Mn, Mo, Se and Zn for one or more fish species (NRC 2011). Age, sex, weight gain and body composition are the biological factors based on which the response criteria for determining mineral requirements should be assessed. In fish, the aquatic environment complicates the matter further with water mineral concentration, salinity and temperature of the rearing medium interacting with biological factors like life stage (age), sex, trophic level, feeding status of the fish and dietary factors like diet composition, bioavailability and nutrient interactions.

**Additives and supplements**

Apart from the above, materials used to nutritionally fortify, complement and supplement the feeds are known as additives. There are several of them. The best and most common examples are vitamin and mineral supplements. Several other examples can be cited depending upon the functionality it can impart to the feeds. The applied aspects of fish nutrition are presented hereafter with an overview of the feed material/stuff used, nutritional requirements of aquatic animals, feed technologies in vogue in fish feed production and feed application.

**Classification of feedstuffs**

Feedstuffs can be classified basically in two. Feed stuffs of plant origin and feeds stuffs of animal/ aquatic /marine origin. Feeds stuff of plant origin are cereals, pulses and several agro-industrial by-products generated in their processing. There are several non-conventional feed resources (NCFR) also. It will not be out of place to mention here that soybean meal is the most popular proteinaceous feed ingredient used in aquafeeds.

The most popular feedstuff of animal origin in aquatic animal nutrition is fishmeal. Fish oil follows. Others are, shrimp meal, squid meal, and other molluscan meals. Rendered animal protein is another group of feed materials immensely popular in replacing fish meal because there is a global effort to reduce the use of fish meal and fish oil in aquatic feeds.

The details of feed stuffs are now available through www.feedipedia.org which is a website maintained by several countries. Feedipedia is a joint project of INRA (Institut National de la Recherche Agronomique, French National Institute for Agricultural Research), CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement, French Agricultural Research Center for International Development, AFZ (Association Française de Zootechnie, French Association for Animal Production) and FAO (Food and Agriculture Organization of the United Nations) – from the website accessed on 26-11-2023.

Nutritional requirements are synonymous with recommended dietary allowances (RDA) in human nutrition. Knowledge of the nutritional requirements of the fish or shrimp which is cultured is essential in the formulation of feeds.

Requirements of protein and energy for different groups of fishes

| Protein | Atlantic salmon | Common carp | Rohu | Tilapia | Catfish | Hybrid striped bass | Rainbow trout | Pacific salmon |
|---|---|---|---|---|---|---|---|---|
| Digestible protein% | 36 | 32 | 32 | 29 | 29 | 36 | 38 | 40 |
| Digestible energy (kcal/kg diet) | 4,400 | 3,200 | 3,200 | 3,400 | 3,000 | 4,000 | 4,200 | 4,200 |

Nutrient requirements of freshwater fish (NRC 2011)

| Parameters | Species | | |
|---|---|---|---|
| | Carp *Cyprinus carpio* | Rohu *Labeo rohita* | Tilapia *Oreochromis* spp. |
| Digestible Protein % | 32 | 32 | 29 |
| Digestible Energy kcal/kg | 3200 | 3200 | 3400 |
| Arginine | 1.7 | 1.7 | 1.2 |
| Histidine | 0.5 | 0.9 | 1.0 |
| Isoleucine | 1.0 | 1.0 | 1.0 |
| Leucine | 1.4 | 1.5 | 1.9 |
| Lysine | 2.2 | 2.3 | 1.6 |
| Methionine | 0.7 | 0.7 | 0.7 |
| Methionine + Cysteine | 1.0 | 1.0 | 1.0 |
| Phenylalanine | 1.3 | 0.9 | 1.1 |
| Phenylalanine + Tyrosine | 2.0 | 1.6 | 1.6 |
| Tryptophan | 1.5 | 1.7 | 0.3 |
| Valine | 1.4 | 1.5 | 1.5 |
| Taurine | NR | NT | NT |

Feed specification for carps.

| Characteristics | CLF | CNF | CSF | CGF | CFF | CBF | Stability |
|---|---|---|---|---|---|---|---|
| Age | Upto age of 15 days/ 25mm length | From 16th day to 90th day/25-100 mm length | From 5g to 100 g in size | From100 g to 500g | From 500 g to harvesting | Before 4 months of the onset of breeding | Water Stability |
| Type | Powder or granules form of size >500 µm | crumbles or pellets of 500-1500 µm diameter | pellets of 1.5-3 mm diameter | pellets of 3 mm to 5 mm diameter | pellets of 4 mm to 6 mm diameter | pellets of 4 mm to 6 mm diameter | Not less than 80% after 20 minutes |
| CP | 35 | 35 | 26 | 22 | 20 | 25 | |
| EE | 6 | 6 | 4 | 4 | 3 | 6 | |
| CF | 6 | 6 | 8 | 8 | 10 | 8 | |
| AIA | 2.5 | 3 | 3 | 3 | 3 | 3 | |
| GE | 3400 | 3400 | 3000 | 2800 | 2700 | 2900 | |

Feed formulation means blending a variety of feed materials based on the nutritional requirements in such a way that, the blend meets the nutritional requirements. Thus, knowledge of nutritional requirements is one of the prerequisites to feed formulation. A summary of the protein and energy requirements given below is from the NRC (2011) publication on the nutrient requirements of fish and shrimp.

Nutrient requirements of marine fish

| Protein | Asian sea bass | Cobia | European seabass | Japanese flounder | Grouper | Red drum | Yellow tail |
|---|---|---|---|---|---|---|---|
| Digestible protein% | 38 | 38 | 40 | 40 | 42 | 36 | 38 |
| Digestible energy (kcal/kg diet) | 4,200 | 4,200 | 4,000 | 4,000 | 4,000 | 4,000 | 4.200 |

The recommended dietary protein level of different marine fish species (NRC 2011)

| Parameters | Weight range | | |
|---|---|---|---|
| | Asian seabass | Cobia | Grouper |
| Digestible Protein % | 38 | 38 | 42 |
| Arginine | 1.8 | | |
| Histidine | | | |
| Isoleucine | | | |
| Leucine | | | |
| Lysine | 2.1 | 2.3 | 2.8 |
| Methionine | 0.8 | 1.8 | |
| Methionine + Cysteine | 1.2 | 1.1 | |
| Phenylalanine | | | |
| Phenylalanine + Tyrosine | | | |
| Tryptophan | | | |
| Valine | | | |
| Taurine | | | |
| Digestible Energy kcal/kg | 4200 | 4200 | 4000 |

IS 16150 (Part 7) Marine carnivorous fish feed

| Characteristics | Fry | Nursery | Starter | Grower | Brood | Stability |
|---|---|---|---|---|---|---|
| | MCFFF | MCFNF | MCFSF | MCFGF | MCFBF | Water Stability |
| | Feed to be fed for fish fry in hapas/ /tank/cage from 0.01 g to 0.5 g size | feed to be fed to fingerlings in tanks/ hapas/cages or ponds from 0.5 g until they reach a size of 10 gm. | feed to be fingerlings in ponds/ tank/cage from 10 g to until they attain a mass about 50 g | feed to be fed to juveniles in ponds/tank/ cage from 50 g to until harvest | feed to be fed to adult fish meant for breeding purpose | stable without disintegration in water for 10 minutes minimum. The water stability shall not be less than 90 percent after 10 minutes when tested |

| | | | | | | |
|---|---|---|---|---|---|---|
| CP | 50 | 45 | 42 | 38 | 45 | |
| EE | 16 | 12 | 10 | 8 | 10 | |
| CF | 3 | 3 | 4 | 4 | 3 | |
| AIA | 2 | 2 | 3 | 3 | 2 | |
| GE | 4300 | 3650 | 3300 | 2900 | 3450 | |

Nutrient requirement of marine shrimp

| | Kuruma prawn | Fleshy prawn | Pacific white shrimp | Tiger shrimp |
|---|---|---|---|---|
| Digestible protein % | 38 | 32 | 30 | 34 |
| Digestible energy (kcal/kg diet) | 4,400 | 3,200 | 3,000 | 3,000 |

**Shrimp gross protein requirements**

| | |
|---|---|
| *Penaeus japonicus* | *40-60%* |
| *Penaeus brasiliensis* | *45-55%* |
| *Penaeus monodon* | *35-50%* |
| *Penaeus aztecus* | *29-51%* |
| *Penaeus merguiensis* | *34-50%* |
| *Penaeus indicus* | *40-43%* |
| *Penaeus setiferus* | *28-32%* |
| *Penaeus stylirostris* | *30-35%* |
| *Penaeus penicillatus* | *22-27%* |
| *Metapenaeus monoceros* | *55%* |
| *Penaeus cailorniensis* | *>44%* |
| *Penaeus kerathurus* | *>40%* |
| *Penaeus vannamei* | *>30%* |
| *Penaeus duorarum* | *30%* |
| *Metapenaeus macleayi* | *27%* |

IS 16150 (Part 3) Fish Feed —Specification, Marine Shrimp Feed

| Physical characteristics | Size | Particle size |
|---|---|---|
| Starter | Up to 7 g | 0.4 - 1.4 mm |
| Grower | 7 -20 g | 1.4 – 2.2 mm |
| Finisher | > 20 g | |
| Water stability | 2 h | Not less than 90% |

| | *Monodon* | | | *Vannamei* | | |
|---|---|---|---|---|---|---|
| CP | 38 | 35 | 32 | 35 | 32 | 30 |
| EE | 5 | 5 | | | | |
| CF | 3 | 4 | 5 | 4 | 5 | 5 |
| AIA | 4 | 5 | 5 | 4 | 5 | 5 |
| GE | 3400 | 3300 | 3200 | 3200 | 3000 | 2800 |

After gaining a fair understanding of the feed stuffs and nutritional requirements of fish/ shrimp the next step would be to formulate feeds.

**Feed formulation**

Feed formulation is a technique, basically mathematical, to arrive at the precise quantity/ies of the feed material to be mixed to arrive at the desired nutritional composition in the feed. This can be a simple mixture of two ingredients such as a proteinaceous one (groundnut oil cake) with an energy-rich (wheat flour) one. As the number of ingredients used and the nutrient specifications increase, the complexities in calculations also increase. Thus, calculations not possible on paper have to be done with calculators and computers. Now, feed formulation software packages are available for commercial purposes at a price and freely also to some extent. The simplest one worth mentioning here is the 'Solver' which is a linear programming 'add-in[1] in Microsoft Excel which can be used for feed formulation. An empirical formulation is shown below.

| Source | Parts per hundred |
|---|---|
| Animal/ aquatic/ marine protein | 30 |
| Vegetable protein | 30 |
| Starch/ carbohydrate | 30 |
| Fat (fish + Vegetable oil) | 5 |
| Mineral salts | 3 |
| Vitamins | 2 |

**Feed technology**

Feed technology deals with the processes and the machines used to produce feed.  Its evolution was demand-driven. When feed material broadcasted as a mash was found to go to waste, mechanisms to make it water-stable were devised. Thus, the mash was converted into a dough ball and fed minimising feed wastage. Till this stage, they were farm-level improvisations. Pelletization is the first step in the mechanization of feed production. By pelleting the feed material with the help of a binder for water stability, technically known as hydrostability was improved. Pelletization initially was a cold process. Later on, cooking using steam was incorporated to obtain a cooked pellet which was nutritionally superior to a cold pellet. As more and more species of fish and shrimp were cultured along with the growth of aquaculture worldwide, the aforementioned pelletization technology was inadequate, because pelletization both cold and cooked could produce only sinking pellets which were suitable to feed only shrimp. Floating and slow-sinking feeds were required to feed most of the freshwater carps, tilapia and marine fish. Besides this, feed consumption could be monitored visually and feed management was more cost-effective. Extrusion, the state-of-the-art in fish feed production became the most widely adopted technology for the production of aquatic feeds with different physical properties like floating and slow-sinking.

**Extruders**

Extruders are of two types; single-screw extruders and twin-screw extruders. Single-screw extruders are used to produce a feed of more than 1.5 mm in pellet diameter for application in grow-out systems and twin-screw extruders are used to produce feeds of less than 1.5 mm known as micro-feeds. Microfeeds are used for feeding larval fish, ornamental fish and fish in their nursery phase. Extrusion as technology was developed for the production of various industrial products. It then found application in ready-to-eat (RTE) foods and is now used for aquatic feed production.

**Larval nutrition**

Larval nutrition is discussed broadly under the heads, Live feeds and feeding, Live feed enrichment – bio encapsulation and micro diets, microbound diets, and microencapsulated diets. The most popular live feeds are phytoplankton followed by zooplankton mainly, rotifers, copepods and artemia. Among the zooplankton, rotifers and artemia are deficient in fatty acids, especially for the altricial marine fish larvae. This is overcome by enriching them with nutrients especially fatty acids through bio-enrichment/ boosting/ bio-encapsulation/ boosting/ metabolization. Copepods are rich in phospholipids with the appropriate fatty acids. The larval stages of copepods are known as copepodites which meet both the size and nutritional requirements of marine fish larvae.

**Larval feeds**

Larval feeds are formulated dry feeds of particle sizes ranging from 100 microns to 1.5 mm which are used to co-feed or replace live feeds. These are the feeds which are also used to feed ornamental fish. Another application of microfeeds is for nursery rearing of food fish to grow them to sizes suitable for stocking them in open water bodies or cages and pens.

**Feeding management**

This is one of the neglected aspects of aquaculture nutrition. What to feed, how much to feed, and how often are the questions to be answered here for cost-effectiveness and resource efficiency? In general, as a thumb rule, it is said that any animal including the human being consumes 2-3% of their body weight as dry matter (excluding water) as food or feed. Bearing this in mind, feed should be made available to the cultured animals. Estimation of the standing stock biomass becomes crucial here. This involves observation and standardization of protocols to be followed. Feeding frequency is another aspect because ration means feed required by an animal over a period of 24 hours. How this quantity of feed is chunked and fed is very important because, if you take the case of shrimp, it is known that they have to be fed every six hours and the ration has to be divided into four doses and applied. During earlier stages of growth, it is not unnatural that the fish and shrimp may consume up to 15% of the body weight as dry matter. Optimising all these aspects skillfully is extremely important.