Feed Formulation for Sustainable Aquaculture

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Abstract

As aquaculture production of tropical fish and crustacean species becomes more intensified, practical diets need to be formulated to be cost effective and environment-friendly. Ingredients should be included to satisfy the nutrient requirements of the animal, promote optimal fish growth, and boost the income of small-scale farmers and commercial producers with minimal impacts to the surrounding environment. Feed formulation for sustainable aquaculture should aim at increasing aquaculture system performance and profitability, enhancing the animals' disease resistance, increasing attractability, palatability, and digestibility of practical diets, and maintaining environmental quality through sound feeding management and good aquaculture practices. More vigorous research and development efforts need to be supported to generate feed technologies that will ensure a steady and reliable supply of safe and high quality aquaculture products to the public while preserving the environment.

Keywords: practical diets, feed formulation, sustainable aquaculture

Healthy and wholesome aquaculture

One of the most important thematic programs of SEAFDEC/AQD is Healthy and Wholesome Aquaculture which is an important strategy towards increasing the productivity of aquaculture systems. Ultimately, by improving performance of the aquaculture system and by maintaining environmental quality, aquaculture will be sustainable for generations to come.

Over the last few decades, increases in aquaculture production have been based on the application of aquaculture feed. Considering that about 60-70% of investment in aquaculture is due to feeds and feeding management and with an annual growth rate of roughly 5% and 75% of production being due to feed taking species, the feed demand exceeds 20 M metric tons annually. At the average percentage of crude protein for the aquafeed of about 30%, the protein requirement exceeds 6M metric tons per year. At this rate, the aquafeed industry cannot continue its dependence on fish meal and will have to find alternative sources of protein.

Feed formulation is the process of combining different feed ingredients in proportions necessary to provide the fish with proper amounts of nutrients needed at a particular stage of production at a reasonable cost. It requires knowledge about nutrients and feedstuffs, nutrient requirements, palatability, acceptability, digestibility, toxicity, as well as costs.

Proper and correct feed formulation as well as good aquaculture practices and feeding management will ensure sustainable aquaculture, aquaculture that is (a) environmentally acceptable to all stakeholders; (b) economically viable depending on the level of economic development of the particular locale or country where the operations take place; and (c) socially equitable, a concept that varies according to the differences in social parameters of a particular society.

To deliver proper nutrition and feeds to aquaculture species, several aspects need to be considered such as nutrient requirements of aquaculture species, sustainability of aquafeed ingredients (sources of raw materials that are environmentally acceptable), improved feed management by improving feed quality, farming of low-trophic level species and integration with other agricultural farming activities.

Feeds for sustainable aquaculture

The aims in formulating feeds for sustainable aquaculture are improved production, higher disease resistance, better attractability and palatability of aquafeeds, and stronger environmental protection.

Improved production and profit

Improved feed composition and better feed conversion efficiency increase fish production, lower feed cost, and minimize the production of wastes from fish farms. A balanced diet for fish is important in ensuring fast growing, healthy, and disease-free fish and shrimps. Giving food that supplies all the components of good nutrition is essential in good aquaculture practices. Nutrients provide energy sources, build tissues, and are able to regulate metabolism in fish and shrimps. These nutrients are carbohydrates, fats or lipids and fatty acids, proteins and amino acids, vitamins, minerals. Nutrient standards for complete feeds have been recommended in the recently published Philippine National Standards for aquaculture feeds. This is the output of the technical working group composed of resource persons from the academe, research and development institutions and the Philippine feed industry upon consultation with major stakeholders in the aquaculture industry in the Philippines (BAFS/PNS 84 - Aquaculture Feeds, 2010).

Carbohydrates include simple sugars, starches, celluloses, gums and related substances that are inexpensive sources of energy giving 4 kilocalories of energy per gram of carbohydrate. Thus, as much carbohydrate as the fish or shrimp can use is usually included in aquaculture diets. They are also used as feed binders (for example, bread flour, carrageenan, agar, and alginates) to make the feed stable in water. Table sugar (sucrose), glucose, lactose, bread flour, wheat flour, corn starch and cassava starch are good carbohydrates and bread flour, wheat flour, and starches are used as carbohydrate sources in fish or shrimp diets.

The ability of fish or shrimps to make use of carbohydrates in their diet varies considerably. Most carnivorous species have limited ability to use carbohydrates compared with omnivorous or herbivorous species. The carbohydrate levels in grow-out diets for various tropical aquaculture species are 25-30% of the diet, 29%, 45%, and 55% for grouper, Tiger shrimp, milkfish, and tilapia, respectively.

Fats or lipids are organic compounds that are important components of biomembranes of animals, plants, and microbes. They are nutrients that are not soluble in water, but are soluble in organic solvents like ether and alcohol. Lipid in the diet of aquatic animals has two main functions – as a source of energy and as a source of essential fatty acids that cannot be made in the body of the animal. In addition, lipids are also important sources of fat-soluble vitamins. Lipids provide a secondary storage of heat and energy in that one gram of fat or lipid gives 9 kilocalories of energy. Fish and shrimps require w3 and w6 -fatty acids in their diets because they cannot make them. The polyunsaturated fatty acids (PUFA) namely: linoleic acid (18:2w6) and linolenic acid (18:3w3), and the highly unsaturated fatty acids (HUFA) such as eicosapentaenoic acid (EPA, 20:5w3), docosahexaenoic acid (DHA, 22:6w3) and arachidonic acid (ARA, 20:4w6), are needed by fish and shrimps. Failure to provide these essential fatty acids in the diet can slow growth and consequently, a prolonged lack of these fatty acids in the diet can lead to death. Animal sources of fats or lipids in fish diets are cod liver oil (CLO), squid liver oil, and beef tallow while the plant sources are soy bean oil (SBO), corn oil, coconut oil, and sunflower seed oil. CLO is rich in w3 HUFAs and SBO is rich in w6 and also w3 PUFAs.

The crude fat levels in grow-out diets for tropical aquaculture species can vary considerably. Diets for marine fish like grouper and milkfish can contain higher levels (11-12%) of fat compared with those of shrimps or freshwater fish like tilapia (4-9%). A 1:1 combination of CLO: SBO is usually used to provide a source for both w3 and w6 fatty acids.

The essential fatty acid requirements of tropical aquaculture species also differ for warmwater tropical fishes or shrimps. Marine carnivores like grouper requires 1% of w3 HUFA from fish oil while a marine planktivore such as milkfish requires 1-1.5% w3 PUFA from fish oil and/or SBO. In contrast, a freshwater herbivore like tilapia needs w6 PUFA from SBO. Tiger shrimp needs 0.5% w3 PUFA and less than 0.5% w6 PUFA from fish oil and/or SBO. The differences are due to the varying adaptations to the combination of the predominant PUFA in the marine environment and the carnivorous preference of marine species. The unsaturated fatty acids in the marine food web are dominated by w3 HUFA originating from marine algae and carnivores consume smaller fish that depend on phytoplankton and zooplankton. The essential fatty acid requirements of freshwater fish can generally be met by w3 PUFA because freshwater microalgae generally have w3 PUFA rather than the w3 HUFA. In addition, w6 PUFA, and not w3 PUFA, can be abundant in freshwater microalgae.

Lastly, increased fish oil in finisher diets leads to increased levels of w3HUFAs in the tissues of fish. This observation has important implications for fish husbandry in ensuring the health, growth and survival of farmed fish as well as in maintaining the quality of fish products because of the benefit of consumption of fish and its content of w3 fatty acids to human health.

Proteins are needed by fish and shrimps for making new tissues (growth and reproduction), and replacing worn-out tissues (maintenance and repair). Proteins function in two ways: They provide the ten essential amino acids (histidine, methionine, arginine, threonine, tryptophan, isoleucine, leucine, lysine, valine, and phenylalanine) which cannot be made in the body of the animal and thus must be obtained from the diet. Proteins are also a tertiary source of energy in that one gram of protein can give 4 kilocalories of energy. Inadequate dietary protein will slow growth and severe lack of protein in the diet can eventually lead to death. Common protein sources in fish or shrimp diets are classified into two – animal sources such as fish meal, shrimp meal, squid meal, and meat and bone meal; and plant sources such as soy bean meal, pea seed meal, cowpea meal, and various leaf meals.

The nutritive value of dietary protein depends on the ability of the protein source to fulfill the essential amino acid requirements of fish or shrimps. The closer the profile of amino acids in the protein source to the requirement level, the higher is the nutritive value of the protein. Thus, the essential amino acids coming from the diet must satisfy the amino acid requirements of the animal to be of any nutritive value.

Complete protein sources are those that contain all the essential amino acids needed by fish or shrimps. Animal protein sources are usually complete proteins. Some protein sources especially plant protein sources lack certain essential amino acids. For example, soy beans lack methionine and are said to be limiting in methionine. Corn lacks lysine and tryptophan and is said to be limiting in these amino acids. It is therefore ideal to have a mixture of protein sources to provide a good amino acid balance needed by the animal.

The essential amino acid requirements for tropical aquaculture species such as milkfish, tiger shrimp and Asian sea bass have been determined (Borlongan and Coloso, 1993; Millamena *et al.*, 1996-1999; Coloso *et al.*, 1999, Murillo-Gurrea *et al.*, 2001, Coloso *et al.*, 2004). Aquaculture diets for these species should be formulated with amino acid levels that conform to the requirement levels for these amino acids for optimum protein efficiency.

The crude protein levels in fish or shrimp diets also vary. Grow-out diets for carnivorous species like grouper contain more protein (44% or higher) and tiger shrimp contain 42% while grow-out diets for omnivorous or herbivorous species such as milkfish or tilapia can contain much less protein (28-32%).

In addition, the crude protein levels in diets for other life stages of tropical aquaculture species are not static and can also vary. Diets for the larval stages contain higher levels of protein (38-50%) to support rapid growth as well as for broodstock stages (44-48%) to support ovarian maturation and production of good quality eggs and larvae.

Vitamins are organic substances that are present in small amounts and are vital for the health and well-being of fish and shrimps. There are two classes of vitamins depending on their solubility characteristics. The water-soluble vitamins are vitamin C, vitamin B complex, folic acid, inositol, choline, and pantothenic acid. The fat-soluble vitamins are vitamins A, D, E, and K. Fish meal, organ meats, leaf meals, yeast and other microorganisms are good sources of vitamins. The vitamin requirements for tropical species have been determined in some species but not in others (Halver, 2002). It is difficult to determine the vitamin requirements of fishes and shrimps because these are in minute amounts, the basal diet must contain purified ingredients free of vitamins, and the water medium must also be vitamin-free. Minerals help to build and maintain the tissues of fish and shrimps and regulate metabolism. There are four major classes: macrominerals – sodium, potassium, calcium, phosphorus, magnesium, sulfur, carbon, hydrogen, oxygen, nitrogen and chloride; microminerals or trace elements –iron, zinc, iodine, manganese, fluoride, copper, selenium, molybdenum, chromium, and cobalt; ultratrace elements- silicon, vanadium, nickel, tin, aluminum, and boron; and the toxic elements- cadmium, arsenic, mercury and lead. Good sources of minerals are fish meal, soybean meal, various leaf meals, seed meals, flour, and rice bran. Aquaculture diets can contain up to 2-4% each of vitamin and mineral premixes. The stable form of vitamin C, magnesium ascorbyl phosphate is used because ascorbic acid is rapidly destroyed upon contact with water. Oftentimes, additional vitamin A and E are also added especially for broodstock feeds.

The two most important factors to consider in formulating a feed for any aquaculture species for improved production are nutrient requirements and feeding behavior of the fish or shrimp. Adequate nutrients must be given to fish or shrimps for faster growth and survival and feeds that are suited to the feeding behavior of animals should be offered. The culturist must know what feed to give to a fish that swallow food whole or shrimp that nibble slowly on their food. Some fish feed on the surface, some on water column, and still others are bottom feeders. Nutrient requirements also vary with various life stages. The culturist must know the nutrient requirements of these life stages to provide good nutrition and ensure rapid growth of the cultured species and minimize the production of waste from the farming activity. Balanced nutrition leads to good growth, low feed conversion ratios, lower production costs, higher profit, and more sustainable production.

Higher disease resistance

All of the essential nutrients discussed in the preceding section should be provided in the diet in adequate amounts to ensure the health of aquatic animals. Several of these nutrients and other components of the diet as well as feeding practices influence the susceptibility of fish and shrimps to various infectious and noninfectious diseases. Diseases of fish can be caused by bacteria, fungi, viruses, parasites as well as environmental and genetic factors. Fish exhibit different tolerances to different environmental conditions and disease agents.

In terms of the dietary components, nutrient deficiencies can adversely affect fish health making them more susceptible to various disease agents. However, dietary supplementation of certain nutrients at levels above the minimum requirements has shown enhancement of some immune responses and resistance to various disease agents. Of the various vitamins that are essential for fish and shrimps, vitamin C and vitamin E have several distinct metabolic effects but they both have antioxidant functions. Higher vitamin C and E levels leads to increased disease resistance perhaps because high tissue levels of these vitamins provide a readily available reservoir for use by the animal to defend itself from disease causing agents. The high levels of these vitamins have shown lower mortalities of fish challenged by bacteria or a stimulation of the nonspecific immune response (Gatlin, 2002).

Nonnutritive dietary components such as the immunostimulant b glucan may also potentially aid in disease control of fish or shrimps. These compounds are polysaccharide derivatives from yeast and fungi and act to stimulate the specific or nonspecific immune response of fish and increase survival (Gatlin, 2002). Other dietary components such as nucleotides have also been shown to enhance antibody production, increase the nonspecific immune response, increase disease resistance and survival. Nucleotides function as building blocks for DNA/RNA synthesis and cell growth, enhance stress tolerance, and enhance disease resistance.

Better attractability and palatability

The overall profitability of aquaculture depends on preventing mortality during the early life stages and maximizing feed utilization during the entire duration of culture. This depends on the physical and chemical properties of the feed to ensure maximum utilization of the nutrients in the feed. It important that fish can efficiently utilize the feed and also that the nutrient components must be stable during manufacture, storage, transport, and feeding. Feeds must have the proper density, odor, size, taste, appearance and must have good binders to make it stable in the water so that nutrients do not leach out in the water before the fish can eat the feed (Pigott and Tucker, 2002). Factors that make diets attractive to fish and palatable include high quality of ingredients, use of fresh oils, fish meals with low biogenic amine content, absence of mold and low tannin content. Use of chemical attractants in the feed for fish and crustaceans is desirable. Attractants include marine based extracts and/or meals, fish meal, fish solubles, squid meal, squid liver meal, squid oil, shrimp meal, shrimp head meal, short necked clams; free amino acids- glutamate, glycine, taurine, arginine, lysine; and others such as glucose, starch, gelatin, casein, pheromones, betaine, putrescine, and cadaverine.

Stronger environmental protection

Better feeding management is required for environment protection and sustainability of aquaculture systems. Excess, uneaten feeds and feces sink to the bottom sediment. Dissolved nutrients and decomposing bottom sediment increase nutrient loading, change the algal composition and production, and changes the nature of the benthic community. These conditions deplete the dissolved oxygen, and increase the production of harmful gases such as H2S by anaerobic conditions having deleterious effects on aquatic organisms. If unabated, the poor environment will cause the gradual deterioration of the ecosystem leading to fish kills and can eventually lead to the eutrophication of inland bodies of water. Eutrophication is the unnatural enrichment of the water with two plant nutrients, nitrogen and phosphorus. The phosphorus (P) requirements (0.29-0.85%) of several fish species are known. In rainbow trout, low dietary P and high vitamin D levels, decrease the soluble and fecal P levels. Low dietary P levels increase P deposition (as % of P intake) in the tissues (Coloso *et al.*, 2001, 2003). However, the use of low P diets are costly thus needs to be regulated. In rainbow trout fed 1.0 or 1.4% dietary P, growth is similar in both diets, but the low dietary P, decrease soluble and fecal P excretions. However, cost of production is higher using low P diets, thus needs regulatory measure (Sugiura *et al.*, 2005). Increased P availability from the diet can also be achieved with supplementation of phytase, an enzyme that liberates the phosphate group from phytic acid content of plant sources making it more available to the animal. Thus, to protect the environment we need to include enough non-protein energy to decrease nitrogen excretion to the environment, reduce feed conversion ratio to minimize impact to the environment, use low P diets to reduce the amount of P excreted to the environment, and use phytase to increase P availability.

Summary and conclusion

The concept of healthy and wholesome aquaculture is an integral component in improving and sustaining aquaculture production to provide fish protein and other beneficial nutrients. Our understanding of the principles of aquaculture nutrition and feed formulation for tropical aquaculture species has vastly improved over the years resulting in better feed formulations and better feeding practices. However, more vigorous R & D efforts in nutrition and fish health management involving various sectors of the aquaculture industry need to continue to ensure a steady, sustainable, and reliable supply of safe and quality fish beneficial to public health while preserving the environment.

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Suggested Readings

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