Fish Feed Technology

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3 Fingerling Feeds

The general practice in fish feed formulation is to reduce the amount of dietary protein in feeds as fish grow. When fish are in the 10- to 100-g weight range, they are fed fingerling diets. Semimoist pellet sizes of $\frac{3}{64}$–$\frac{3}{32}$ inch (1.2–2.4 mm) cover this range, and dry, compressed feeds are fed as crumbles to fish at the lower end of their weight range and as $\frac{3}{32}$ to $\frac{1}{8}$ inch (2.4- to 3.0 mm) pellets to larger fish. Growth rates are higher during this stage than in later stages of the life cycle. Thus, it is essential to ensure that the growth potential of the fish is realized by feeding a diet that is slightly overfortified with limiting amino acids (protein) and with vitamins. Nearly all of the information on fish nutritional requirements has been obtained from studies with fish in this size range. This information allows fingerling feeds to be formulated quite precisely.

4 Grower Feeds

Grower feeds are formulated to promote efficient and economical growth of fish from the fingerling stage up to market size. Formulations for these fish contain less protein and more energy than fingerling formulations. The energy content and proportion of the total dietary energy derived from protein must be carefully formulated to ensure that protein retention is high, that is, a high proportion of dietary protein is used to synthesize tissue protein rather than metabolized to yield metabolic energy. The majority of feed fed during a production cycle, often more than 90%, is fed during the grower stage. Most fish nutrition research has also focused on this type of feed because of the massive quantities required during production. Grower feeds are formulated for maximized growth of fish that are past early development, have a fully developed digestive system, and readily consume manufactured diets. Feed cost and feed conversion ratios (FCR) are very important factors to consider when selecting grower feeds. Small changes in feed costs or FCR can have a major impact on the profitability of a fish farm.

5 Broodstock Feeds

Somatic growth continues uninterrupted in most fish species until a combination of external and internal factors initiates sexual maturation. The temporal aspects of the sexual maturation process in fish are variable, proceeding for weeks or months, depending upon the species. During sexual maturation, somatic growth slows and gonadal growth accelerates until the fish spawns. In many species of cultured fish, feeding ceases during part or all of the maturation process. If the fish is a species that survives spawning, feeding then begins again sometime after spawning. Research on the nutritional requirements of broodstock is both time-consuming and expensive, but some information is available to guide feed formulation (Luquet and Watanabe 1986; Hardy 1985). Relative to other life stages the knowledge base on the specific dietary nutrient requirements of maturing fish is limited. Salmonid broodstock perform relatively well when fed slightly modified grower diets. Marine species, such as sea bass, require omega-3 (ω-3) fatty acids during ovarian development. Generally, formulations contain higher levels of protein, energy, and certain vitamins associated with the conversion of maternal tissue nutrients to egg nutrients. Ascorbic acid levels are often increased in broodstock feeds, given the fact that, in some species, egg levels are relatively high. For salmonids, it is necessary to supplement diets with carotenoid pigments, such as astaxanthin, to ensure viable offspring (Christiansen *et al.* 1995).

6 Low-Pollution Feeds

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In recent years salmon and trout aquaculture has been under increased scrutiny by regulatory agencies for the level of nutrients leaving hatcheries in the effluent water. Since hatchery effluents are a point source of pollution that is easy to sample compared to nonpoint sources, pressure has grown to reduce the concentration of several nutrients in hatchery effluents. The primary nutrient or materials subject to regulation so far are phosphorus and fecal solids. Nitrogen may be the next nutrient to be considered by regulatory agencies.

For years, phosphorus levels in salmonid feeds were unintentionally high for economic reasons; fish meal was the main constituent of salmon and trout feeds. Regular fish meal contains high levels of phosphorus as a result of its fish bone content. Fish meal was such a high proportion of salmon and trout feeds because it was usually relatively inexpensive, was very palatable, and supported high growth rates because of its favorable profile of essential amino acids. Reducing phosphorus levels in salmonid feeds required feed formulators to reduce the proportion of regular fish meal, and this has proved difficult without increasing feed ingredient costs.

Several approaches have been taken to reduce phosphorus levels in effluents. The first involved more precise estimations of phosphorus requirements for all life stages of salmon and trout (Rodehutscord 1996; Ruohonen *et al.* 1999; Sugiura *et al.* 2000b). In addition, low levels of phosphorus could be fed during the final month or two of the grow-out stage in trout farming without decreasing growth rates (Lellis, Barrows, and Hardy, unpublished data, 2001). The fish utilized their stored phosphorus reserves from their skeleton and other hard tissues to supply their needs for growth. Additional research showed that large trout have a lower dietary phosphorus requirement than do small trout, making it possible to lower the phosphorus content of grow-out trout feeds (Sugiura *et al.* 2000b).

The second approach to phosphorus reduction has been to increase the level of available phosphorus in the feed so that a higher percentage can be utilized by the fish. Increased digestibility, coupled with reduced dietary levels, results in less phosphorus being excreted in the feces and urine. Plant protein sources, such as wheat and corn gluten, contain lower levels of phosphorus than protein sources of fish or animal origin. The apparent phosphorus digestibility is similar to that in fish meal (Sugiura and Hardy 2000). Modification of fish meals has also been an area of active investigation (Babbitt *et al.* 1994). Mechanically deboning the fish meal prior to drying, or employing air classification to remove bone particles in dry meals, appears to offer two benefits. First, the total level of bone (ash fraction) and, thus, phosphorus is decreased. This allows for the processing of previously unusable meals such as seafood processing waste, which is mostly heads and frames after filleting, into usable fish meal. Second, the phosphorus availability increases as the bone component is removed, as a result of lower levels of calcium in the product (Sugiura *et al.* 2000a).

Phosphorus availability can be increased using feed additives. Phytate is the storage form of phosphorus in seeds, e.g., corn, wheat, barley, and soybeans. Phytate phosphorus is unavailable to fish and all other simple-stomached (monogastric) animals, including humans. The shift from animal protein to plant protein to lower total feed phosphorus levels has resulted in an increase in the level of Phytate phosphorus in feeds. Phytate phosphorus passes through the gut of the fish and is excreted, thus contributing to phosphorus levels in hatchery effluents or ponds. The addition of phytase, a natural enzyme in seeds that releases phosphorus from the Phytate complex as seeds sprout, increases the phosphorus availability in fish. Phytase is commercially produced by several companies and is added to poultry and swine feeds. Phytase activity increases with temperature; its maximum activity is at 50–55°C. Thus, its activity in fish varies with water temperature. It is more effective in warmwater fish, such as catfish and tilapia, than in coldwater fish. Phytase can also be added to feed ingredients to treat them prior to their being used in feeds (Cain and Garling 1995).

Preliminary studies have suggested that the addition of citric acid to trout feeds increases phosphorus digestibility in grow-out-size rainbow trout (Sugiura *et al.* 1998b; Vielma *et al.* 1999). However, feeding diets containing citric acid to first-feeding rainbow trout lowers fish performance. This approach to increasing the phosphorus digestibility in trout feeds, even though promising, needs further research before it can be implemented.

Another approach to reducing solids production is to increase the overall digestibility and energy content of the diet and thus decrease the total amount of feed fed. As mentioned, high-energy diets, over 25% total lipid, are being fed to Atlantic salmon and rainbow trout. Fecal solids production can be further reduced by pelleting feeds using extruders or expanders that cook the carbohydrate portion of the feeds, eliminating the need for indigestible binders. These feeds yield lower feed conversion ratios compared to traditional steam-pelleted feeds. Extruded and expanded feeds are comprising an increasing portion of the aquaculture feed market in the United States. Very high energy feeds are not fed as widely in the United States as in Europe, perhaps due to differences in the consumer acceptance of high-lipid products produced by feeding very high energy diets and, also, due to differences in the size of fish (trout) at harvest.

Modification of feeds to produce intact fish feces is another area of current research. Culture systems using quiescent zones where particles can settle and off-line settling basins for further settling are being used at many farms and hatcheries to capture insoluble nutrients and total solids. However, some of the feces break up into particles too small to settle from the water column and escape in farm effluents. If dietary changes that produce intact, high-density fecal pellets can be identified, further reduction in total solids and perhaps dissolved nutrients in hatchery effluents could be achieved.

Each of the approaches to pollution reduction is best applied to fish in the grow-out phase or with broodstock because of the large quantities of feed used during these stages. The amount of starter feed fed during a production cycle is so small that even complete elimination of phosphorus excretion would not significantly affect the total phosphorus discharges in effluents during the production cycle of the fish. The small gains in phosphorus reduction are not worth the risk of lowering fish performance in the early life stage.

7 Feeds to Increase Immunocompetence or Seawater Transfer

In some culture situations, disease outbreaks occur on a seasonal basis and special feeds are fed slightly before an outbreak period to help the fish fight disease. Supplements include vitamins, especially vitamin C, glucans, and other compounds reported to stimulate the immune system of the fish. In salmon farming, small changes in formulation are made for feeds that are supplemented before, during, and after fish are transferred from freshwater hatcheries to seawater farms. Betaine, which is reported to help some species of salmon make a successful transfer to seawater, especially during out-of-season transfers, is a supplement sometimes added to seawater transfer diets.

8 Feeds for Recirculation Systems

Interest in using recirculating systems for aquaculture has increased rapidly in the last few years. Fish farms in certain areas of the United States, such as the upper Midwest, use these systems, which employ filtration equipment to remove both particulate materials and dissolved nutrients from the water. These substances originate from the feed and thus a feed formulation or manufacturing technique that lowers the workload of the filtration system should increase production and/or lower production costs. Specifications for feeds designed for recirculating systems are similar to those for pollution reduction feeds, but even more restrictive, especially with respect to the dietary mineral content. Research and production of feeds formulated specifically for use in recirculation systems will be a growing sector of fish nutrition in the next decade.

9 Product Quality Feeds

Product quality feeds are those that are fed to fish to increase the quality of the product in the market. The development of product quality feeds is an area in which there is more potential than accomplishment in fish feed formulation, but the development of finishing feeds for domestic livestock illustrates the potential for development of product quality feeds for fish. At present, product quality in salmonids and red sea bream is enhanced by dietary carotenoid supplementation. Other potential changes in product quality feeds include formulation adjustments to manipulate the lipid content and fatty acid composition, and percentage dress-out, and dietary supplementation with α-tocopheryl acetate to reduce oxidation of lipids during frozen storage (O'keefe and Noble 1978; Boggio *et al.* 1985). The flavor (odor) of fish can be modified by diet, especially the dietary lipid source. Texture has been reported to change slightly when the dietary lipid source is changed, but more research is needed to confirm this.