Aquaculture Nutrition and Product Quality

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A Brief Overview of Fish Nutrition

Aquaculture can be simply defined as the culture of aquatic organisms (fish, crustaceans, and shellfish) and plants. These organisms and plants can be cultured in freshwater or marine environments. While aquaculture has been practiced for several thousand years in some parts of the world, it has only been recently that intensive production of some species has been adopted. Under this type of production, the cultured organism is stocked at a high density and grown as rapidly as possible to reach marketable size. Traditionally, when fish or crustaceans are stocked at low densities in earthen ponds, little to no diet needs to be provided to the organism, which can rely on the natural foods present in the pond for a majority of their nutritional requirements. However, as higher stocking densities are used, there is a decreased contribution that natural foods can make to the organism's nutritional needs and thus, a complete prepared diet needs to be fed to the culture organism. However, by feeding a prepared diet, the producer could affect the quality of the product and its desirability to consumers.

Fish require the same nutrients that all animals require for proper growth, health, and reproductive status. These include protein, lipids, minerals, vitamins, and energy. The following can serve as a brief introduction to fish nutrition and the effect of diet on product quality of cultured products.

Protein

Proteins are organic compounds that are comprised of polypeptide linkages. Proteins always contain carbon, hydrogen, oxygen, and nitrogen; however, some proteins (amino acids) also contain sulfur, iron, and phosphorus. Plants generally contain their protein in the actively growing portions of the plant such as leaves and seeds, while animals tend to have their protein deposited in muscle, organs, bones, skin, scales, and feathers. The basic structural units of a protein are amino acids. There are ten essential amino acids that cannot be synthesized by vertebrates, including fish, and must be supplied by the diet in levels that meet or exceed the specific amino acid requirement of the organism. These ten essential amino acids are arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. The non-essential amino acids can be synthesized by transfer of an amino group to alpha-keto acids which can be made from non-protein sources, such as glucose. These non-essential amino acids include alanine, asparagine, aspartic acid, cysteine, cystine, glutamic acid, glutamine, glycine, hydroxyproline, proline, serine, and tyrosine.

There are a number of factors that affect the protein requirement of fish. One is the size of the fish; small fish require more protein than larger fish. A second factor is protein quality. While two different diet ingredients may have the same crude protein value, digestibility and availability of amino acids may be vastly different which affects the ability of the fish to utilize that ingredient. A third factor is water temperature. Since fish are cold-blooded organisms (poikilothermic), when water temperature is not near the optimum for growth, a lower dietary protein level can be fed. A fourth factor is feeding rate whereby if a fish is fed to satiation (all it will consume), a lower protein level can be fed. A fifth factor is the presence of natural foods in the culture environment. Lastly, the dietary energy level can affect protein requirements of fish. If the non-protein energy level is low, the fish will utilize protein to meet its energy needs, which is financially wasteful and inefficient. If the energy level is too high, it may suppress food consumption so that the fish will not meet the protein (amino acid) requirements and reduced fish growth will occur.

Lipids

Lipids, often erroneously referred to as "fats," include fats, oils, sterols, and waxes. By technical definition, fats are esters of glycerol and fatty acids that are solid at room temperature; oils are esters of glycerol and fatty acids that are liquid at room temperature; sterols are lipids that do not contain glycerol; and waxes are esters of fatty acids with alcohols other than glycerol. Other important lipid groups include phospholipids, lipoproteins, and glycolipids. Lipids are essential nutrients in fish diets and contain carbon, hydrogen, and oxygen. However, since lipids have a higher proportion of their molecules comprised of carbon and hydrogen than proteins or carbohydrates, lipids are an ex-

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tremely dense fuel source, releasing approximately 9.0 kcal of gross energy per gram.

Fatty acids are the structural components of lipids. The length of the fatty acid (carbon) chain and the degree of saturation (if there are double bonds present within the fatty acid) are critical to the physical and nutritional properties of lipids. In terms of chain length, most biologically important fatty acids for fish have between 16 and 22 carbon atoms. Saturation has a profound effect on the qualities of fatty acids. When a single bond joins two carbon atoms together, the carbon atoms within the chain have two hydrogen atoms associated with each carbon. One carbon at the end of the chain has three hydrogen atoms associated with it. The carbon at the other end of the chain has a carboxyl group (COOH) associated with it; the carbon has a double bond with the oxygen atom and a single bond with the hydroxyl (OH) group. If all the bonds within a fatty acid chain are single bonds, then that fatty acid is said to be "saturated" (all carbons are saturated with two hydrogens). When carbon atoms within the chain have one or more double bonds between the carbons, the affected carbon atoms have only one hydrogen associated with each carbon and are termed "unsaturated." Fatty acids with one double bond are termed monoenoic; two double bonds are termed dienoic; and three or more double bonds are termed polyenoic. These polyenoic fatty acids are also called polyunsaturated (or highly unsaturated) fatty acids (PUFA or HUFA).

Lipids are used for several major functions in the body: they provide energy, provide essential fatty acids, and serve as structural components in cell membranes and other tissues. Some fish require a dietary source of essential fatty acids while other fish can synthesize essential polyunsaturated fatty acids from smaller-chain fatty acids. For instance, rainbow trout (*Oncorhynchus mykiss*) can elongate (add carbons) and desaturate (add double bonds) to linolenic acid (18:3n-3) and bioconvert it into the polyunsaturated fatty acids eicosapentaenoic acid (20:5n-3) and docosahexaenoic acid (22:6n-3). However, some freshwater fish and many marine fish cannot bioconvert linolenic acid into EPA and DHA and must be provided these essential fatty acids in the diet. Some fish, such as the channel catfish (*Ictalurus punctatus*), do not have a high requirement for n-3 HUFA, while other species, such as tilpaias, require the n-6 HUFA, arachidonic acid (20:4n-6).

Vitamins and minerals

Vitamins are organic substances that are essential for growth, health, reproduction, and maintenance, but required in small amounts. Vitamins cannot be synthesized since fish cannot synthesize vitamins at all or in insufficient quality for normal development, growth, and maintenance, they must be supplied in the diet. Each vitamin performs a specific function in the body and this one vitamin cannot substitute or replace another vitamin. Vitamins can be classified into two groups: fat-soluble vitamins and water-soluble vitamins. The fat-soluble vitamins are comprised of vitamin A, vitamin D, vitamin E, and vitamin K; water-soluble vitamins include biotin, choline, folic acid, niacin, pantothenic acid (B_3), riboflavin (B_2), thiamin (B_1), pyridoxine (B_6), cyanocobalamin (B_{12}), and vitamin C (ascorbic acid). The fat-soluble vitamins contain carbon, hydrogen, and oxygen, while water-soluble vitamins contain these three elements plus nitrogen. Fat-soluble vitamins are absorbed from the intestinal tract in the presence of lipids, and any condition or factor that increases lipid absorption will increase the absorption of fat-soluble vitamins. Absorption of water-soluble vitamins is simpler because water is constantly absorbed from the intestine into the bloodstream.

Water-soluble vitamins not stored in the body and excess vitamins are excreted; however, excess fat-soluble vitamins can be stored in the body. Excesses of these vitamins in fish diets may cause physiological or health problems and adding excess amounts of those vitamins may not only be financially wasteful, but also may compromise the well-being of the fish. Not all the vitamins present in diet ingredients are in available forms. For instance, niacin in many cereal grains is burned to protein and cannot be absorbed unless the ingredient is treated with an alkali. Further, vitamins are destroyed during diet production due to oxidation or heating, and vitamins may be lost during storage due to oxidation, heat, sunlight, or mold growth. Thus, some vitamins may need to be added to the diet in excess of requirements due to the anticipated losses during diet processing, production, and storage.

A mineral is an element that is found in ash when a food or body tissue is burned. Minerals are classified into either macrominerals, elements that are required in large amounts, (from a few tenths of a gram to over a gram per day), and micorminerals. Microminerals are also called trace minerals because they are required in very small amounts (from micrograms to milligrams per day). The general functions of minerals include: add strength to the skeletal system, serve as components of organic compounds (such as proteins and lipids), enzyme-system activators, and maintain acid-base and osmotic balances.

Diet Formulation and Processing

Factors other than essential nutrient requirements of the animal influence ingredient composition of formulated fish diets. Some of these are related to desired physical properties in the feed, environmental and management conditions under which the diets will be used, availability of ingredients, and economics.

Most commercial warmwater fish diets made in the United States are extrusion-processed which allows them to float on the water surface. This is a valuable management tool for large pond feeding because it allows the feeder to determine how much the fish are consuming. Gelatinized starch, coming from cereal grains, is important for the feed particles to expand during extrusion. Commercial diets containing a minimum of 30% corn or other whole grain usually expand satisfactorily. Fiber and supplemental fat in the ingredient mixture reduce expandability during processing. Thus, supplemental fats should not be added to the diet until after extrusion, and highly fibrous feedstuffs, such as wheat bran, should not be used in large quantity.

Pelleted diets (processed by compression) also must be firmly bonded for satisfactory water stability. Firm bonding is especially important when the pellets are to be crumbled into smaller particle sizes for small fish. The same ingredient restrictions recommended for extruded diets also apply to pelleted diets. Non-nutritive organic binding agents, such as hemicellulose or lignin sulfonate, may be added to pelleted diet formulations at the rate of 2% to 2.5%.

Small-particle diets for feeding very small fish will lose water-soluble nutrients by leaching in water. These diets should be over-fortified with the water-soluble vitamins. The addition of fat to the surface of small particle diets improves water stability and allows them to float, providing easier access by the fish.

Commercial aquaculture diets must be formulated and manufactured to take into account processing and storage losses. Ascorbic acid (vitamin C) is especially sensitive to deterioration during diet processing and storage. Approximately 40 to 60% of ascorbic acid is lost from catfish diets during extrusion and 15 to 20% during pelleting, and the half-life of ascorbic acid in catfish diets stored in outdoor sheds was 2.8 months during the summer. Other vitamins sensitive to extrusion are vitamin A (palmitate beadlets), riboflavin, pyridoxine (hydrochloride), and thiamine (mononitrate). Vitamin losses under the prevailing processing conditions should be determined, especially for extruded diets, in order to adequately over-fortify with the necessary vitamins. Except for vitamin C, storage losses of water-soluble vitamins are not large. Storage losses of A, D, and E may be significant but the use of antioxidants can minimize this.

Since there are over 280 different species of fish, crustaceans, and shellfish that are currently cultured worldwide, knowledge of the culture and environmental conditions that the diet will be used are almost as important as the species to be fed. Nutrients from aquatic organisms make slight to significant contributions to the dietary requirements of fish raised in ponds. The magnitude of this nutrient contribution depends upon pond fertility, size and number of fish, and feeding habits of the fish. Efficient planktonic and benthic feeders, like Tilapia species, have gained 3000 kg/hectare in six months with only pond fertilization. Fish such as tilapia, when fed in fertile ponds, do not need supplements of micronutrients in their formulated diet, and can probably utilize inexpensive diets with a high energy-to-protein (DE/P) ratio. In contrast, channel catfish obtained only 2.5% of their protein requirement and 0.8% of their energy requirement from pond organisms. It has been found that at standing crop of 3,000 kg/hectare, which is much below current pond culture practices, the addition of a vitamin premix to the diet formula increased growth significantly. Consequently, nutritionally complete diets are recommended for pond-cultured catfish.

Warm water food fish cultured in temperate zones should be fed during cool weather to maintain weight and disease resistance; however, the nutrient density of the diets can be reduced. It has been found that a 25% protein diet was effective as a 35% protein diet in maintaining weight of channel catfish in ponds over winter. Feeding rate influences the nutrient content of the diet for maximum growth rate of fish. Fish grown in large ponds are often fed at rates below satiation to avoid wasting diet. Channel catfish fed a 30% protein diet to satiation daily gained more than those fed 12.5% less diet, but when a 35% protein diet was fed, growth was the same for the two feeding rates. Less diet was wasted and feed efficiency was greater when each diet was fed at the lower rate. Because of the importance of minimizing wasted diet in intensively-stocked cultured ponds, feeding to satiation and achieving maximum levels of dry matter or energy intake may be feasible. If this practice were followed, readjustment in ratios of energy to protein and other nutrients from those determined under maximum feeding conditions would be necessary.

Small fish have higher protein requirements than larger fish. With terrestrial food animals the nutrient composition of the diet is changed as the animal increases in size. For channel catfish, only two types of commercial diets are fed: a starter diet (from hatch to approximately 12 g in size) which contains 35 to 40% protein, and a grower diet (from 12 to 500 g in size) which contain 30% to 35% protein. Catfish diets fed in ponds do not change in nutrient composition increase in size for the following reasons: 1) there is imprecise knowledge of the nutrient requirements of post-fingerling size fish: 2) a common culture practice is to have fish of various sizes, is in the direct progression with size increase in pond-raised fish.

The effect of the diet on body composition of the fed fish is important in food fish. Excessive fattiness reduces slaughter yield in processed fish and reduces the keeping quality of frozen stored fish. Further, consumers eat fish because of the low-fat nature of the product. Higher fat levels in the fillet of fish may not meet with consumer acceptance. However, higher body fat levels are not necessarily bad. Salmon and trout with a high percentage of body fat when released into streams or lakes may have higher chances of survival. And many people eat trout and salmon for their high levels of "heart-healthy" fatty acids eicosapentaenoic acid and docosahexaenoic acid (both omega three highly unsaturated fatty acids). Other warm water fishes, such as bait-fish and ornamentals, and those grown for restocking in recreational fishing ponds may benefit from higher dietary digestible energy (DE) levels than fish grown for food.

Diet Manufacturing Processes

Aquaculture diets are manufactured in feed mills. Regardless of whether a feed is floating or sinking, the general scheme of feed manufacture is similar. Whole grains are ground through a hammer mill prior to batching. The diet ingredients are batched, weighed, mixed, and then reground. After re-grinding, mixed diets are either extruded (floating diet) or steam-pelleted and then cooled or dried, screened, and fat is added. Fat is generally sprayed on to the finished diet pellet just prior to being loaded into trucks for bulk delivery or prior to bagging.

In the receiving and storage phase of diet processing, diet ingredients are received at the mill either by rail or by truck. Rail is generally more economical. Ingredients are unloaded from the railcars or trucks and transferred to storage houses or bins. As ingredients are needed, they are moved by conveyers or screws to the appropriate section of the feed mill for processing. The ingredients must be ground to an appropriate size for pelleting.

For steam-pelleted (sinking) diets, moisture, heat, and pressure are used to form the ground diet ingredients into a compact pellet. Steam is added to the ground feed ingredients to increase the moisture level to 15 to 18% and temperature to 75 to 80ºC. Steam helps to gelatinize starches, which bind the feed particles together. However, the use of pellet binders, such as hemicellulose, starch glutens, and greater variation in ingredient selection and processing conditions produce pellets of excellent quality and water stability. The hot mash is then forced through a pellet die in a pellet mill. Die size is dependent on the size of pellet desired. The pellets exit the die at about 10% moisture; thus, require little drying but the diet must be cooled. Steam-pelleted diets are generally less expensive to manufacture than extruded (floating) diets because less energy is expended in their manufacture. Also, less destruction of nutrients occurs during steam pelleting as compared to extrusion. However, use of a sinking diet may not allow farmers to observe feeding behavior in the fish they are feeding. Thus, a floating diet is required.

Producing a floating diet involves the cooking of mixed diet ingredients in the barrel of an extruder by a combination of pressure, heat, and friction. Diet ingredients are a mixture of starchy and proteinaceous materials that are moistened to form a mash. The mash may be preconditioned in a conditioning chamber for 3 to 5 minutes during which moisture is added in the form of steam (water can also be injected) to increase the moisture level of the mash to about 25%. During this period, the mash is cooked as moisture penetrates the diet as the mash passes to the extruder. Temperatures in the extruder generally range from 90 to 150ºC and are generated from friction in the extruder. The superheated mixture is then forced through a die located at the end of the extruder barrel. The die restricts product flow thus causing development of the necessary pressure and shear. As the ingredient mixture passes through the die, a sudden reduction in pressure results in the vaporization of part of the water in the mixture and the pellets expand. The moisture level of the pellets leaving the extruder is higher (18-21%) than that of steam-pelleted feed; thus, extruded pellets must be dried at high temperatures for longer periods of time.

Steam-pelleted diets exit the die at a moisture level of about 10% and do not require heat for drying. Extruded diets also lose moisture by flash evaporation and evaporative cooling, but require additional drying since they contain 20% or more moisture. Floating diets should be dried to a moisture content of 8 to 10%. Drying is generally accomplished using a multi-stage dryer, which has different temperature zones (135-150ºC). After drying, diets are sometimes passed through screens to remove fines and the pellets are then sprayed with fat prior to being loaded into trucks for delivery to the fish farm, or bagged for shipment to retail markets.

Aquaculture Diets and Their Effects on Product Quality

Product quality for aquaculture products (fish, crustaceans, or shellfish) can be dramatically affected by the diet fed to the organisms. Diet can affect the smell, taste, color, texture, firmness, and nutritional quality of the edible portions of the animal. Further, in today's climate, food security and safety issues have become increasingly important. Harmful contaminants may be passed to the organism via the diet. Accountability of the food people eat has led several industries, such as the beef and poultry industries, to begin to be able to have the origin of the meat and the diet fed to the animal known and traceable at all times prior to slaughter and processing.

For aquaculture products, there is beginning to be developed systems where country of origin is labeled, and each country has its own guidelines and regulations on importation of cultured and fishery products. Aquaculture diets fed to fish and crustaceans can affect the consumer appeal, nutritional content, and storage quality of the edible portion. Thus, preferences of each must be known to ensure that any possible alterations due to diet fed are acceptable to consumers.

Appearance

The color, freshness, and appearance of cultured fish and crustaceans are of vital importance to consumers; however, for most species, they are little affected by the diet fed to the animal. This statement is not true for the salmonids, where the characteristic pink or red color of the fillet is important to the consumer who is used to these flesh colors being associated with high quality. Carotenoids are used in the diet to add this color to the flesh and this addition represents a significant expense to the cost of producing the diet. Astaxanthin is the carotenoid generally added to the diet for coloration in salmonids, but is poorly absorbed and is not retained in the muscle very well (about 10-15% of the dietary intake is retained in the flesh; Torrissen *et al.* 1989). Absorption has been shown to be enhanced by increased lipid levels in the diet (Bjerkeng *et al.* 1997) and Pozo *et al.* (1988) reported that dietary canthaxanthin was utilized better in rainbow trout (*Oncorhynchus mykiss*) when dietary vitamin E (alpha-tocopherol) was added. However, Jensen *et al.* (1998) did not report this result when they fed dietary alpha-tocopherol to fish.

Texture and taste

The texture of meat, whether it is beef or fish, is of importance in consumers' decision to purchase the product. Texture can be described as the tenderness, chewiness, and moisture (dryness/juiciness) content of the meat. Many people already test meat for texture by poking the meat to see how it feels. If it does "not feel right," the person will probably not purchase the product. In the food sciences, there are instrumental measurements that can be made with meat to quantify texture. The Instron Universal Testing Machine is routinely used along with sensory analyses, to measure and quantify texture quality of fresh and stored fish fillets, although only a few studies have been conducted. It has been reported that inclusion of high levels of lipid in diets fed to rainbow trout resulted in softer (less firm) fillets compared to fillets from fish fed diets containing less lipid (Andersen *et al.* 1997).

Izquierdo *et al.* (2003) stated that flesh quality of gilthead seabream (*Sparus aurata*) was not affected by partial replacement of marine fish oil (anchovy oil) with vegetable oils (soybean oil, rapeseed oil, or linseed oil) except that there was a significantly stronger smell and taste of fish fed the soybean oil diet compared to fish fed the marine fish oil diet. Texture analysis indicated that no significant differences were found in hardness (deformation), maximum charge (kN), contraction at maximum charge (mPa), and deformation at maximum charge (mm).

For sea bass (*Dicentrarchus labrax*), no differences were found in texture analysis or organoleptic analysis between fish fed a diet containing a marine fish oil compared to fish fed diets in which vegetable oils partially replaced the marine fish oil (Izquierdo *et al.* 2003). This is in contrast to Glencross *et al.* (2003) who stated that organoleptic evaluation of fillets of red seabream (*Pagrus auratus*) fed diets containing canola oil and soybean oil were different than fish fed a diet with a marine fish oil added.

Fillet composition

While it has been stated that cultured fish tend to be better than wild fish (Haard 1992), this depends greatly on fish size, fish age, nutritional status (type of diet fed and feeding regime used) of the fish, and season. Addition of dietary lipid may increase lipid levels in the fillet; however, many fish species seem to have the ability to utilize high dietary lipid levels with minimal increase in fillet lipid deposition. Hung *et al.* (1997) fed white sturgeon (*Acipenser transmontanus*) diets containing 26%, 36%, and 40% lipid and found no differences in lipid content of whole-body. Hillestad *et al.* (1998) fed Atlantic salmon (*Salmo salar*) diets containing 22% or 30% lipid are reported no differences in lipid content of dressed carcasses. However, Hemre and Sandnes (1999) fed Atlantic salmon diets containing 31%, 38% and 47% dietary lipid and stated that there was an increase in fillet fat from 7.7% (for fish fed the diet containing 31% lipid) to 16% (for fish fed 47% lipid) as a wet-weight basis.

Webster *et al.* (2001) reported that fillet composition of hybrid striped bass (*Morone chrysops* X *M. saxatilis*) was not affected by feeding regime when grown in outdoor cages. Fish were fed either once daily, twice daily, once every other day, or twice every other day. While growth was greatly affected by feeding regime, fillet composition (percentage protein, lipid, fiber, and ash) was similar among all treatments. However, the percentage abdominal fat in fish fed once daily and twice daily was significantly higher than in fish fed either once every other day or twice every other day. This was due to the fish in the first two treatments being much larger than the fish in the latter two feeding regimes. Likewise, fillet yield in hybrid striped bass fed either once daily or twice daily was higher than in fish fed the two other feeding regimes. These results are in agreement with a previously published paper using a shorter feeding period in which sunshine bass were grown in aquaria (Thompson *et al.* 2000).

Dietary protein level can affect whole-body composition of fish. It has been reported that juvenile hybrid bluegill (*Lepomis cyanellus* X *L. macrochirus*) fed diets containing 40, 44, and 48% protein had significantly higher whole-body protein percentages compared to fish fed a diet containing 35% (Webster *et al.* 1997). However, these authors reported that there were no differences in the amino acid composition of the fish among any treatment.

The fatty acid composition of fish tissues is dependent upon many factors including fatty acid composition of the diet, ability to desaturate and/or elongate highly unsaturated fatty acids (HUFA) from their respective 18-carbon precursors, season, size and age of fish and nutritional status of the fish. Some species of fish is a good source of obtaining n-3 HUFA that are "heart healthy." These include eicosapentaenoic acid (EPA; 20:5 n-3) and docosahexaenoic acid (DHA; 22:6n-3). Some fish species, particularly marine fish species, require dietary n-3 HUFA, while other fish, such as the channel catfish (*Ictalarus punctatus*) do not. Further, rainbow trout can elongate and desaturate linolenic acid (18:3 n-3) to EPA and DHA so these letter fatty acids do not need to be added to a diet. Other fish, such as tilapia, require the n-6 HUFA arachidonic acid (20:4n-6) that must be supplied by the diet. One reason why salmon is widely consumed is because it has an abundance of n-3 HUFA. These must be supplied in the diet by the use of marine fish oils. Use of plant oils (low in n-3 HUFA) to partially or totally replace marine fish oils in diets for salmonids has been shown to cause no adverse effects of growth, but to reduce the n-3 HUFA levels in the fillet.

For salmon diets, marine fish oil is often used as the principal lipid source for high-energy diets. However, it has been become apparent that use of marine fish oils in aquaculture diets may exceed supplies by the year 2010 (Tacon 1998). Thus, use of alternative lipid sources (generally of plant origin) has been evaluated in salmonid diets (Dosanjh *et al.* 1984; Hardy *et al.* 1987; Greene and Selivonchick 1990; Rosenlund *et al.* 2001). Since plant lipids have different fatty acid compositions than marine fish oils, there is some question as to whatever fish growth and quality will be adversely affected.

Rosenlund *et al.* (2001) reported that other Atlanic salmon (Salmo salar) were fed diets with different lipid sources, fillet composition, but not fillet texture and color parameters, were affected. Highest fat levels was found in salmon fed a diet containing 50% of the lipid compound of soybean oil while salmon fed a diet containing linseed oil resulted in lower fillet fat levels. No diet-dependent differences were found for fillet texture and color (Rosenlund *et al.* 2001); however, this is in contrast to Thomassen and Rosjo (1989) and Waagbo *et al.* (1993) who reported that use of high levels of vegetable oils resulted in adverse changes in fillet quality of salmon. Use of a "finishing diet" (a diet that can be fed to fish prior to sale) to alter the fatty acid composition of fillets towards a more consumer-approving profile can be fed to fish towards the end of their growing cycle, while use of vegetable lipids can be used in grow-out diets.

Since manipulation of fatty acid composition of aquaculture diets can result in altered fatty acid profiles of the fish fillets, careful consideration needs to be given to using diets with high levels of vegetable oils as partial or total replacement of marine fish oils when feeding fish, especially marine fish and salmonids. Consumers have equated n-3 HUFA as "heart-healthy." Thus, any reduction in levels of these fatty acids may be viewed negatively by consumers.

Storage quality

The storage quality of aquaculture products is another parameter that is highly important for the industry since consumers want fish and shellfish that will taste, smell, and have desirable texture attributes after storage on ice or frozen. Oxidation of fish lipids can result in off-flavor and rancidity. Antioxidants in the diet, such as vitamin E, selenium, and ascorbic acid, can enhance oxidation stability of fish fillets during fresh and frozen storage. When stored at refrigerated temperatures, lipids in meat oxidize and unsaturated fatty acids form hydroperoxides that are subsequently cleaved to secondary reaction products, such as aldehydes, ketones, and alcohols. These secondary products are generally responsible for the off-flavors of the meat.

Disintegration of this collagen (Type V) fiber in fish fillets results in the softening (Hallet and Bremner 1988; Sato *et al.* 1991) of the fillet. This "mushy" quality may not be desirable to consumers. This is especially true for marine and freshwater crustaceans where consumers prefer a firm-textured meat (such as shrimp or lobster). In a study that evaluated the storage quality of a freshwater crustacean, Tseng *et al.* (2002) reported that Australian red claw crayfish (*Cherax quadricarinatus*) tails that had been stored on ice for up to 14 days had little proteolytic changes and that the myosin heavy chain and actin seemed resistant to proteolysis, especially within the first five days of storage. After 5 days of storage, tail proteins began to denature. This is in agreement with Tseng *et al.* (2003) who reported similar results when red claw tails were subjected to various freeze-thaw cycles.

Food Safety

Dioxins, other organic contaminants (such as polychlorinated biphenyls or PCBs), and heavy metals (cadmium, lead, and copper) are contaminants that may accumulate in an animal, even fish and shellfish. Most heavy metals rarely accumulate in muscle tissue, being preferably deposited in organs (intestine, kidney, and liver); however, cultured fish and shellfish would most likely be free of such metals due to the need to maintain acceptable water quality within the culture environment. Dioxins have been examined, especially in Europe, where in the early years of the new millennium, dioxins were found in high levels in poultry diets. However, aquacultured products in the United States have extremely low levels of contaminants and have always been way below the levels established by either the U.S. Environmental Protection Agency (EPA) or the Food and Drug Administration (FDA) as being unsafe for human consumption. Thus, aquacultured products are a very safe consumer choice.

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