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Aquaculture Feed and Seafood Quality

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Abstract：Seafood continues to be an important protein source in many less developed countries, and over the past decade, the proportion of per capita seafood consumption produced by aquaculture has steadily grown to nearly half. Capture fisheries production has declined in recent years, and projections are for seafood landings to remain constant or decline further in the future. As a result, aquaculture production must increase to meet the expected future demand for seafood. The challenges for aquaculture in the 21st century will include not only quantity to meet increasing demand but also maintaining seafood quality for health consideration. Consumers expect safe and nutritious seafood.

Seafood quality includes characteristics such as appearance, color, texture, and taste as well as very low levels of contaminants and high levels of important nutrients. Unlike seafood harvested from the sea, the quality of aquaculture products can be controlled by many factors from the production phase to the dinner table. This report will discuss how factors such as pond management and feeding contribute to seafood quality.

Since farmers manipulate all nutrient inputs to farmed fish via the feed, the nutrient composition of farmed fish can be controlled to some degree by altering the composition of feed. For example, the color of the skin or, in salmonids, muscle tissue, can be modified by the source and quantity of carotenoid pigments, such as astaxanthin, in the feed. Replacing fish meal and oil with vegetable protein and oils or changing the oil content in fish feed will change the odor and fatty acid composition, and consequently the taste of farmed fish. Muscle lipid content can affect the texture of fish fillets as well. As far as food safety is concerned, wild fish are exposed to contaminants via their prey whereas farmed fish contaminants come from feed. Levels of contaminants in fish feeds can be closely monitored and feed formulations can be altered to reduce contaminant exposure of farmed fish to very low levels. This paper is an overview of a presentation at the workshop "Seafood Quality and Aquaculture" held in October, 2007 in Hawaii related to aquaculture feed. Manipulating the nutrient composition or boosting a selected chemical component in farmed fish products can increase the value of products and also deliver health benefits to consumers.

Key words : seafood quality, safety, feed, nutritional contents, sensory attributes

Soto (2008) recently reported that aquaculture production contributed 49% of total available seafood for human consumption in 2007. Given the fact that capture fisheries landings have not grown during the past decade and are not expected to grow in the future, the continued growth of aquaculture production was key to maintaining a constant per capita seafood supply over the same period. Because landings from capture fisheries are not expected to increase, aquaculture production must increase to meet seafood demands from an ever-increasing world population. At the same time, consumers are

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raising their expectations that seafood, from both capture fisheries and aquaculture, is both safe and nutritious.

For both farmed and wild fish, both biotic and abiotic factors contribute to fish quality starting as early as before the fertilization of eggs and continuing all the way to the dinner table. Most of the quality attributes of both wild-caught and farmed fish are the same; however many attributes can be controlled under farming conditions whereas they cannot be controlled in wild fish. For example, wild fish experience seasonal periods of food abundance and scarcity as well as variations of food type while farmed fish are fed throughout the year using feed provided by farmers.

It is generally accepted that farmed fish quality can be influenced by the formulation or composition of their feed. This is a potential advantage for farmed fish over wild fish, but one that the aquaculture industry has been slow to exploit. This report focuses on the influence of feed on seafood quality. Information presented in this report is based on the presentations at one of Aquaculture Information Program workshops "Seafood Quality and Aquaculture" held at Oceanic Institute in Hawaii in 2007 and review of current literatures.

Quality is one of the most abused words in seafood research as Alasalvar (2002) pointed out. Here we defined seafood quality as the characteristics of food that are acceptable to consumers included external factors (appearance, texture, and flavour) and internal factors (chemical, physical and microbial). Safety of seafood is also included in quality considerations.

Some species of fish have been found to contain relatively high levels of mercury and persistent organic pollutants (POPs) including PCBs, PBBs, and dioxin, and are not considered as a good quality seafood for consumption. Those contaminations can be from feed or being cultured in polluted areas, such as the Great Lakes and Puget Sound in Washington State (O'Neill *et al.,* 1998). This report will only review the quality change as a result of feeding.

Effects of feed on sensory attributes

The common sensory attributes of fish that are evaluated as part of farmed fish quality control are skin or fillet color, texture, flavor, and odor. One must keep in mind that sensory preference can vary among different cultures. Of these attributes, color, flavor and odor can be readily modified by changing feed formulation. Texture is less easily modified in fish, but there are reports that fish muscle texture can be modified by adding algae supplements to fish feeds (Nakagawa and Montgomery, 2007). Texture is thought to be modified by increasing muscle collagen and insoluble collagen fractions within muscle tissue, and by decreasing muscle lipid content. Sufficient information has been developed to provide some insight into the ways in which diet composition can influence sensory attribute of farmed fish.

Color is a critical sensory attribute of salmon and trout fillets. Consumers expect salmon fillets to be reddish-orange in color. In addition, skin color of some species of marine fish, e.g., red sea bream, porgy and similar species reared as food fish, is an importance attribute that dictates value in the market. Color in fish results from deposition of carotenoid pigments in skin and flesh. Astaxanthin and canthaxanthin, the primarily carotenoid pigments of value in food fish, cannot be synthesized by fish and therefore must be obtained from the diet both wild and farmed fish. Feeds for farmed fish must be supplemented with carotenoids to obtain pigmented skin or flesh. Carotenoid sources used in fish feeds can be obtained from natural sources, such as shrimp or krill meal, the marine algae *Haematococcus pluvialis* or Phaffia yeast, or from industrial production in the case of the major carotenoid pigments used in salmon and trout feeds, astaxanthin and canthaxanthin. A target level of carotenoid pigmentation in salmon fillets is equal to or greater than 4 $\mu g/g$ wet tissue (Torrissen *et al.,* 1989). At this level of pigmentation, fillets meet consumer expectations. Higher levels of pigmentation can be achieved, but the human eye has difficulty detecting higher levels, so no additional value is associated with higher fillet carotenoid levels.

Flavor and odor are related sensory attributes, but involve different senses, namely taste and smell. Of the two, the sense of smell in humans is many orders of magnitude more developed than is the sense of taste. With respect to flavor of fisheries products detected by solely taste, very little can actually be modified by nutritional input. Actually, most of the potential for altering the flavour of fisheries products involves changing the odor. Odors in fish can be detected in uncooked products and in cooked products. Generally speaking, odors are stronger in cooked products due to the release of cellular contents which become aerosols associated with conversion of cellular water to water vapour. Many descriptors are used to characterize the flavor/odor of seafood, such as grassy, fishy, musty, metallic and so on. Trained taste panels can characterize fish products based upon descriptors.

Researchers have known for decades that certain feed ingredients alter the sensory attributes of farmed fish. Channel catfish, for example, were characterized as smelling or tasting fishier when feeds contained menhaden oil were compared to feeds containing plant oil (Dupree *et al.*, 1979). Rainbow trout were described as less fishy when sunflower oil replaced fish oil in the feed (Skonberg *et al.*, 1993). Rainbow trout fed a plant protein-based feed were described as being less sweet and having less odor intensity than trout fed a fish meal-based feed (de Francesco *et al.*, 2004). However, replacing herring oil with swine fat in rainbow trout diets did not significantly alter flavor of rainbow trout (Boggio *et al.*, 1985), suggesting that such comparisons most likely only reach significant levels when the fish oil being replaced has a strong fishy odor. Good quality herring oil smells less fishy than equivalent menhaden oil.

Efforts to alter sensory attributes of farmed fish must take into consideration the preferences of the target consuming population. For example, until recently USA consumers expected salmon fillets to be pigmented (red) and trout fillets to be unpigmented (white). This situation is beginning to change. In Europe or Japan, in contrast, rainbow trout fillets are expected to be pigmented. US consumers consistently show a strong preference for fisheries products that do not smell or taste fishy, whereas, consumers in Africa are reported to have a preference for fisheries products that have a stronger fishy component.

Effects of feed on nutritional content

Fish are high-quality sources of protein and essential amino acids, essential fatty acids, vitamins and minerals required in human diets (Nettleton and Exler, 1992). They are also relatively low in saturated fatty acids and total fat relative to other protein sources, such as beef or dairy products. The protein content of fish is relatively constant in a given species, changing slightly with fish size (Shearer, 1994). With the exception of starvation, feed input has little effect on protein content of fish muscle. The amino acid content of fish muscle tissue is excellent in terms of matching the dietary requirements of humans but it is more-or-less fixed in muscle tissue because the main proteins found in muscle, actin and myosin, have fixed amino acid compositions. Thus, protein content or amino acid profiles are not among the components in seafood that can be greatly modified by diet.

In contrast, both total lipid (fat) content and the proportion of individual fatty acids respond to changes in dietary input. Lipid content of fish, under normal growth trajectories, increases with fish size but it can be further increased when fish are fed high-energy diets such that dietary energy intake exceeds the amount required for normal metabolism, growth and activity (Grisdale-Helland and Helland, 1997; Jobling and Johansen, 2003).

Fatty acid profiles of farmed fish reflect dietary fatty acid profiles. For example, rainbow trout fed diets containing plant oils, such as canola oil, exhibit fatty acid profiles more similar to canola oil than fish oil. Similarly, trout fed diets supplemented with marine fish oil exhibit fatty acid profiles similar to marine fish oil. The fatty acid profiles of fish can be altered by changing the lipid source in the diet, but the degree of change depends upon the amount of diet (and lipid) consumed over a given period of time. If, for example, a trout was fed a feed containing primarily canola oil for the first 250 g of weight gain, then switched to a diet containing primarily fish oil for the next 250 g of weight gain, the final fatty acid profile of the fish at 500 g total weight would reflect a combination of canola and fish oil fatty acids, similar to what would result had the fish been fed a diet containing mixture of the two oils throughout the 500 g gain feeding period. Fatty acid deposition in fish appears to follow a simple dilution model (Jobling, 2003). Fatty acid turnover in lipid depots is relatively slow, unless a fish undergoes a prolonged period of starvation or very low feed intake. Under normal fish farming conditions, there are no periods of starvation or low feed intake, at least in intensive fish farming systems.

Consumers' perception of seafood is based in part on its healthful attributes, including fillet highly unsaturated fatty acid (HUFA) content. Therefore, it is critical that farmed fish products contain levels of HUFAs that are sufficient to maintain the healthful attributes expected by the consuming public. Feeding a diet containing a combination of marine fish oil and plant oil results in lower HUFA levels in fillets than would occur had marine fish oil been the sole lipid source in the diet (Bell *et al.*, 2001). However, fillet HUFA content can be increased by feeding a finishing diet containing a high level of marine fish oil during the final phases of production. Studies with salmon and trout show that amounts of HUFAs, expressed on a g/100 g serving size, can be significantly increased by feeding a finishing diet containing marine fish oil such that the total amount of HUFAs per serving are as high or higher than that found in wild fish, although the percentage of HUFAs may be slightly lower.

Levels of some vitamins can also be increased in edible fish tissue by supplementing the diet of farmed fish. Ascorbic acid and fat-soluble vitamin levels (vitamins A, D, E and K) increase in fish tissues in proportion to dietary levels in salmonids and presumably other species of farmed fish. Levels of water-soluble vitamins (B-vitamins), with the exception of ascorbic acid, are less responsive to dietary supplementation at dietary levels higher than required levels. Excess amounts are simply excreted. Tissue levels of essential minerals, such as calcium, phosphorus, zinc and others, are maintained within a narrow physiological range in all animals, and while dietary supplementation can increase whole-body mineral levels in deficient fish, once levels reach levels corresponding to maximum tissue saturation; further supplementation does not increase tissue levels further. An exception to this is selenium, which increases in response to dietary intake due to limitations in homeostatic control when dietary intake exceeds the capacity of fish to excrete excess amounts. A similar situation occurs in the case of heavy metals, e.g. mercury, as discussed under seafood safety.

Effect of feed on safety of farmed fish products

The feeds of farmed fish can be formulated and produced to be virtually free of toxic compounds, thereby ensuring that farmed fish are among the safest products available to consumers compared to wild fish and other sources of protein.

A number of potential hazards, such as (1) methylmercury, (2) persistent organic pollutants (POPs), and (3) chemotherapeutics contamination of fish tissues occurs mainly via the feed.

Methylmercury

Mercury exists in several forms in the environment, but the form of concern in fisheries products (and all foods) is methylmercury, a methylated form of elemental mercury that is synthesized by micro-organisms and passed up the food chain to fish. Farmed fish are fed feeds that are mainly composed of plant products, such as soybean meal, corn gluten meal, and ground corn or wheat, plus fish meal, fish oil, and rendered animal products. Fish meal and fish oil are typically produced from small, short-lived pelagic fish, such as anchovies, sardines, capelin and menhaden, all unlikely to contain high levels of methylmercury. None of the plant or animal-derived ingredients is considered to be a major or even a minor source of methylmercury. Unsurprisingly, farmed fish contain negligible levels of methylmercury. The only way that fish feeds could conceivable contain significant amounts of methylmercury would be if they contained fish meal produced from trimmings of large tuna, marlin or swordfish, or if a localized population of freshwater fish from an area contaminated with methylmercury were used to produce fish meal.

POPs

POPs are organic chemicals that persist in the environment, concentrate up the food chain, and are toxin to humans, wildlife and the environment. POPs are widespread in the environment and are present in detectable levels (ppb) in nearly all fish, birds and terrestrial animals. Thus, POPs are a potential threat to humans if levels in food are high. Due to the lipophilic nature of POPs, they tend to accumulate in fatty tissue, such as the liver. Muscle tissue of most fish consumed by humans is relatively low in lipid, except for certain species, notably salmon and trout among farmed species.

Among the five species of salmon, long-lived, large species like chinook salmon (average life span 4–5 years) have higher concentrations than shorter-lived, small species like pink salmon (two-year life cycle). Compared to common food items, however, neither species is near the top of the list with respect to PCB concentration. The same holds true for farmed salmon, but, in contrast to wild salmon, farmed salmon POP intake can be lowered by diet, thereby reducing POP levels in fillets to very low levels (Ikonomou *et al.*, 2007).

PCBs and other POPs are found in trace amounts in nearly all feed ingredients, but higher levels are found in marine protein and oil, notably oil. Therefore, the nutritional approach to reducing intake of POPs in farmed fish is to reduce levels of marine protein and oil in the feed, or to use marine proteins and oils that are low in POPs as fish feed ingredients. Recently, new technology has been employed by the fish meal and oil industry to remove POPs from fish meal and oil using activated carbon (http://www.999.dk/). This approach results in very low POP levels in fish meal and oil, and virtually eliminates exposure to farmed fish from these ingredients. Past studies concerning the presence of elevated levels of POPs in farmed salmon (Hites *et al.*, 2004) do not reflect the current situation in farmed salmon (Ikonomou *et al.*, 2007). Given the known benefits of fish consumption associated with omega-3 fatty acid intake and other dietary factors, the benefits of fish consumption have been estimated to outweigh the risks for most consumers by a factor of 100 to 1 (Mozaffarian and Rimm, 2006).

Chemotherapeutant residues

To the extent that many chemotherapeutics are administered via the feed, preventing residues is a feed issue. However, it is primarily a compliance issue rather than a production issue. For chemotherapeutics that are allowed, strict rules are in place in many countries concerning withdrawal periods prior to harvest to eliminate the risk of chemotherapeutic contamination of farmed fish products. In countries having well-developed and technologically advanced aquaculture industries, such as Norway, Scotland, Canada and the USA, disease prevention is the preferred method of health management, and as such, the use of vaccines and feed additives to stimulate the immune system of farmed fish has largely replace antibiotic therapy. In this context, the use of immune stimulants and probiotics to enhance fish health deserves mention as a nutritional strategy to improve the quality of farmed fish products.

In addition to nutritional approaches to modify sensory attributes and nutritional content of farmed fish, feed supplements that produce healthy fish in top physiological and metabolic condition also must be considered in any fish farming system to ensure pre-harvest quality standards are met. The subject of feed supplements that influence health and quality of farmed fish has recently been reviewed (Nakagawa *et al.*, 2007). There are a number of feed supplements that act by modifying biochemical pathways in cellular metabolism, but there is no consensus yet concerning their efficacy. As a result, many nutritional approaches to fish quality are still being developed and evaluated in a variety of farmed fish species and culture systems. One approach that has been embraced involves the use of immunostimulants. As the name implies, immunostimulants are supplements added to feeds to stimulate the immune system of animals and fish, and thereby enhance fish health and reduce losses to disease. Immunostimulants include natural products derived from seaweed, yeast, and plants. Active ingredients in such supplements include β-glucans and nucleotides. A number of commercial immunostimulant products are available in the market and many commercial feed manufacturing companies include these products in their feeds. Although there are a number of reports showing product efficacy, immunostimulants are not 'silver bullets' in the sense that they prevent disease in farmed fish. Rather, they are one element of many aspects of feeds and culture technology, including vaccination, that fish farmers must employ to minimize losses to disease and to ensure quality fish are produced for the consumer.

Effects of feed on storage properties

The higher the level of antioxidants in a tissue, the longer lipid oxidation is prevented. Altering the fatty acid composition of fish tissues to reduce the content of polyunsaturated fatty acids (PUFAs) and increase the level of saturated fatty acids was once proposed as a means of increasing storage stability (Cowey *et al.,* 1979) but this approach is not recommended as it would affect the primary healthful attribute of fish consumption, namely omega-3 fatty acid level.

Supplementing feeds with α-tocopherol (Vitamin E) at levels significantly higher than the dietary requirement increases tissue levels of α-tocopherol, the most effective cellular antioxidant, in a dose-response manner. In living tissue, α-tocopherol can be regenerated after losing a proton, but once fish are harvested, regeneration stops and the level of α-tocopherol decreases if conditions are favourable for the initiation step in lipid oxidation. Supplementing channel catfish feed with α-tocopherol reduced lipid oxidation in fillets during frozen storage (O'Keefe and Noble, 1978). A more elaborate study using rainbow trout was conducted by Boggio *et al.* (1985) in which both dietary α-tocopherol level and lipid source varied in feeds. Dietary levels of added α-tocopherol were 0, 50, 500 or 1500 mg kg^{-1}. The dietary requirement of trout for α-tocopherol is 30 mg kg^{-1} (Halver, 2002) and the recommended dietary level is 50 mg kg^{-1} (NRC, 1993). Dietary lipid source, either fish oil containing a high proportion of highly unsaturated fatty acids or swine fat containing a low proportion of highly unsaturated fatty acids, had no effect on frozen storage stability of fillets, whereas dietary α-tocopherol level influenced both α-tocopherol and malonaldehyde levels in fillets. Malonaldehyde, a product of oxidizing polyunsaturated fatty acids used to judge the degree of oxidation, was measured using a 2-thiobarbituric acid method. The highest level of protection from lipid oxidation was observed at the highest level of α-tocopherol supplementation.

Conclusions

The aquaculture industry must strive to improve transparency for consumers in their production techniques, and make the facts available to consumers who wish to learn more about farmed fish products. The additional challenges include reaching some agreement on target quality characteristics for established species, such as salmon and trout, for color, flavor and odor, lipid content and especially omega-3 fatty acid content of edible tissues, e.g., fillets. The consumer wants assurance that fisheries products are safe and nutritious. Only farmed products can guarantee this on a consistent and predicable basis.

Having control of the details of production of farmed fish not only offers opportunities to enhance sensory attributes of fish to fit consumer tastes, but also controls nutritional content for the characteristic of fish of most value in terms of human health, namely omega-3 fatty acid content. By using science-based nutritional approaches, farmed fish can be produced to meet target quality characteristics on a consistent basis. Altering the nutrient content of feed can improve product quality in terms of sensory attributes, content of specific nutrients, and post-harvest storage stability. The quality of farmed fish can be controlled to a large extent by feeding level, nutrient levels in feed, ingredient selection, and protein/lipid ratio of the feed fed during the latter stages of production.

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This is the most recent book we found addresses current information on the effects of nutrients on health and quality of cultured fish. The main contents include Quality and health of cultured fish, Evaluation of quality of cultured fish, Fish health assessment, Essential nutrients, Vitamins, Amino acids, peptides, Lipids, Minerals, Natural substances, Microorganisms, Terrestrial plants, Algae, Chitin, Plant saponins, Nucleotides, Future strategies, Nutrinogenomics. We recommend this book for additional reading.