IMPACTING THE HEALTH AND PRODUCTION OF CULTURED FISH THROUGH ADJUSTMENT OF NUTRIENT AND INGREDIENT FACTORS

by Mark Newman

Aquaculture Feed and Nutrition Specialist

U.S. Soybean Export Council (Southeast Asia) Ltd
541 Orchard Road, #11-03 Liat Towers, Singapore 238881
Tel: +65 6737 6233, Fax: +65 6737 5849
Email: Singapore@ussec.org, Website: www.ussec.org

TECHNICAL BULLETIN
USSEC SEA 06/2021
AQ2021-09

IMPACTING THE HEALTH AND PRODUCTION OF CULTURED FISH THROUGH ADJUSTMENT OF NUTRIENT AND INGREDIENT FACTORS

Introduction

As greater amounts of high-quality seafood products are produced to supply the rising demand created by the world's increasing human population, aquaculture production is trending toward more intensive production systems. Increasing production intensity decreases the amount of natural foods available for the cultured animals and creates increasing reliance on formulated feeds to produce fast growth of healthy fish (Lovell, 1989). The health of cultured fish affects feed consumption, growth rates, mortality, harvest potential, and essentially the economic viability of aquaculture operations. It has long been known that deficiency of a required nutrient in a fish diet will create not only a nutritional disease (Roberts and Bullock, 1989), defined as "the deficiency, excess, or improper balance of the components present in a fish diet (Snieszko, 1972), but predisposes fish to infectious diseases (Ghittino, 1989). So, an understanding of the influence of nutrition on fish health is required for the planning of successful, modern aquaculture operations.

The effect of nutrition on fish health has been reviewed extensively (Roberts and Bullock, 1989, Ghittino, 1989, and more recently, Lee et al., 2015). Dietary nutrients and additives fall within the purview of this review. The objective of the present work is to provide an overview of practical aspects of the effects of nutrition on fish health cultured at relatively high densities.

Positive or Negative Effects of Nutrition on Fish Health

Feeding a nutritionally balanced diet to cultured fish imparts several benefits to fish health. First, there are many documented nutritional diseases that are directly caused by nutrient deficiencies or imbalances in the diet. Clinical symptoms, such as muscular dystrophy, anemia, fin necrosis, hemorrhage, cataracts, scoliosis, and many others can be directly attributed to deficiencies of vitamins or other nutrients in the diet. Feeding a complete, balanced diet will avoid these nutritional diseases. Secondly, it is known that deficiencies of dietary nutrients cause nutritional stress in fish, causing a series of physiological and biochemical changes within the fish, which if severe enough will reduce the immune-competence and will make them increasingly vulnerable to infection. Thirdly, many cases have been documented in which vitamins or certain minerals that are boosted in the diet above levels required for optimum growth, or the inclusion of certain additives in the diet, can improve the innate and/or adaptive immune functions, thus increasing disease resistance and reducing mortality upon disease challenge.

Effects of Macronutrients on Fish Health

Energy and Protein

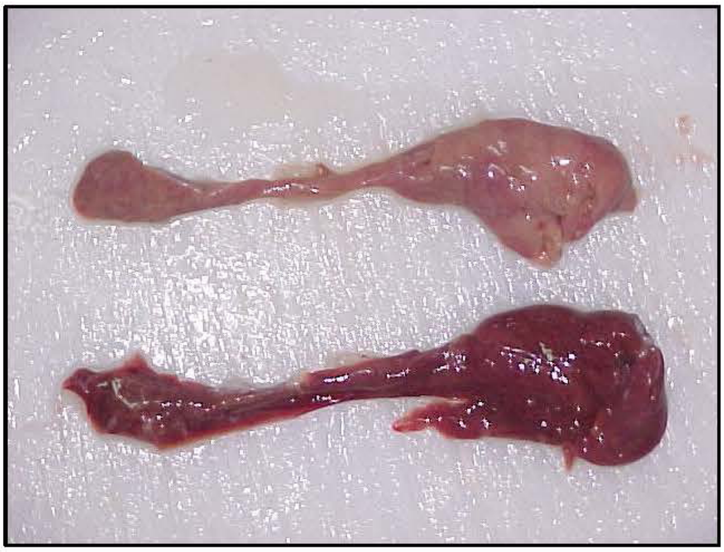
Macronutrients are defined here as protein, lipids, and carbohydrates, and their constituent components. Energy, derived from protein, lipids, and carbohydrates, is included here as well. Although it has been shown that an energy deficiency in feeds for fish causes immune depression (Kiron et al., 1995) and that rainbow trout fed protein-deficient diets had reduced resistance to Infectious haematopoietic necrosis (IHN) virus (Kiron et al., 1993), it is not expected that deficiencies of energy and protein in commercial diets would normally be severe enough to affect the immune response of fish. Energy and protein levels are closely tied to the performance of commercial feeds, so whereas some commercial feeds do not have optimal balances of protein and energy, severe deficiencies are not expected.

However, deficiencies of the essential amino acids, lysine, methionine, and tryptophan, caused by formulation errors, suboptimal processing, or the presence of antinutritional factors, could lead to dorsal/caudal fin erosion, cataracts, or scoliosis, respectively (NRC, 2011).

Digestible Energy: Digestible Protein Ratio:

Amino acids and carbohydrates can be converted to fats, and dietary lipids can be reesterified to fats following digestion. High digestible energy intake combined with low protein quantity or quality can result in a large proportion of retained energy deposited as fat (NRC, 2011). With extreme imbalances of dietary digestible energy (DE) to digestible protein (DP) ratios, fatty livers can be observed (Fig. 1). This condition can result in fish mortality. Lowering the DE:DP ratio in the diet can correct the problem if caught early enough (Fig. 1).

Figure 1. Fatty liver (above) in tilapia caused by high dietary ratio of digestible energy to digestible protein as compared to healthy liver (below) (Photograph courtesy of Tim O'Keefe)



Lipids

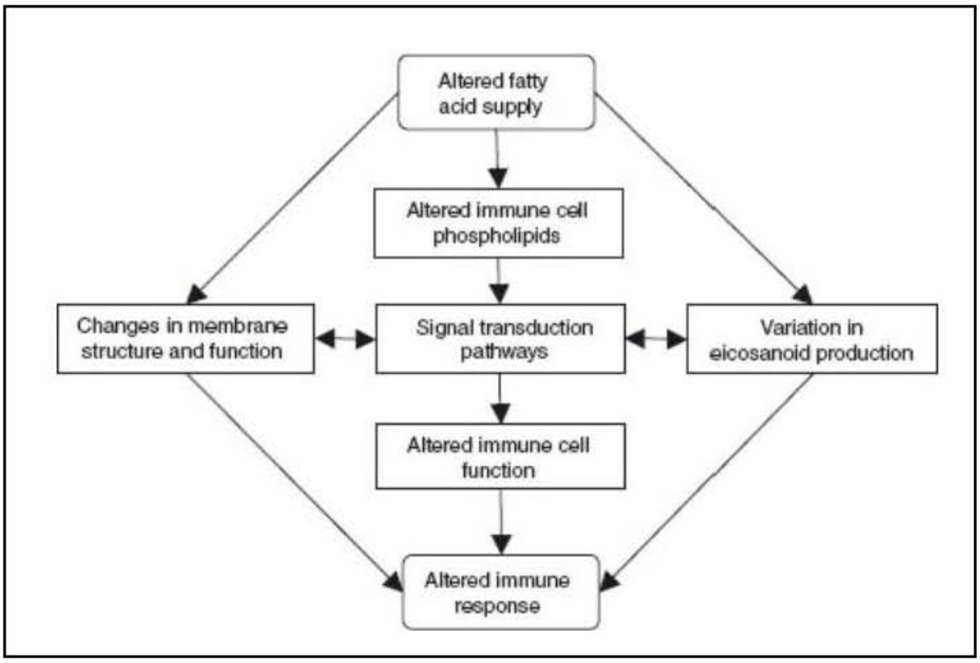
Lipids are an important source of energy for fish, as well as providing essential fatty acids. According to NRC (2011) deficiency of essential fatty acids results in various pathologies. The animal stops growing and reproducing, and eventually dies (Das, 2006). Fatty acids, as components of phospholipids, are important to the structure and function of cellular membranes, and affect the immune system (Verlhac Trichet, 2010). In addition, fatty acids are required as precursors to, and regulators of, the highly bio reactive eicosanoid hormones, including prostaglandins, leukotrienes, and lipoxins. These are hormones produced by cells to act in their immediate vicinity. Eicosanoids are involved in blood clotting, renal and neural functions, and the inflammatory response in disease resistance and adaptation to stress.

Rainbow trout showed a range of pathologies caused by fatty acid deficiency including: erosion of the caudal fin, myocarditis, and shock syndrome, as well as an increased sensitivity to stress (Castell et al., 1972).

Adding as little as 0.5% total omega 3 fatty acid to tilapia diets that were deficient in essential fatty acids significantly decreased mortality in intensive cage culture (Personal communication, Tim O'Keefe).

It is assumed that dietary supplementation with Omega-3 long-chain fatty acids is beneficial for the health of marine fish through modulation of both inflammation and immune cell function (Fig. 2).

Figure 2. Mediation of effects on immune function through changes in dietary fatty acid supply Derived from Calder (2007)



Phospholipids are important components in cellular membranes. The reported requirements for phospholipids is 8-12% of the diet for larval fish and 2-4% of the diet for juveniles (NRC, 2011). No requirement of phospholipids for adult fish has been defined.

Carbohydrates

There is no minimum requirement for carbohydrates, however, increasing digestible carbohydrate in fish diets increases the blood glucose peak (NRC 2011).

Glucose clearance from the blood is more efficient in warmwater herbivorous and omnivorous fish than in cold water carnivorous species. Legate et al. (2001) found that 250 mg/kg body weight of glucose injected into rainbow trout and black bullhead increased blood glucose 250% over basal levels. But return to basal levels took 30 minutes in the bullhead and 24 hours in the trout.

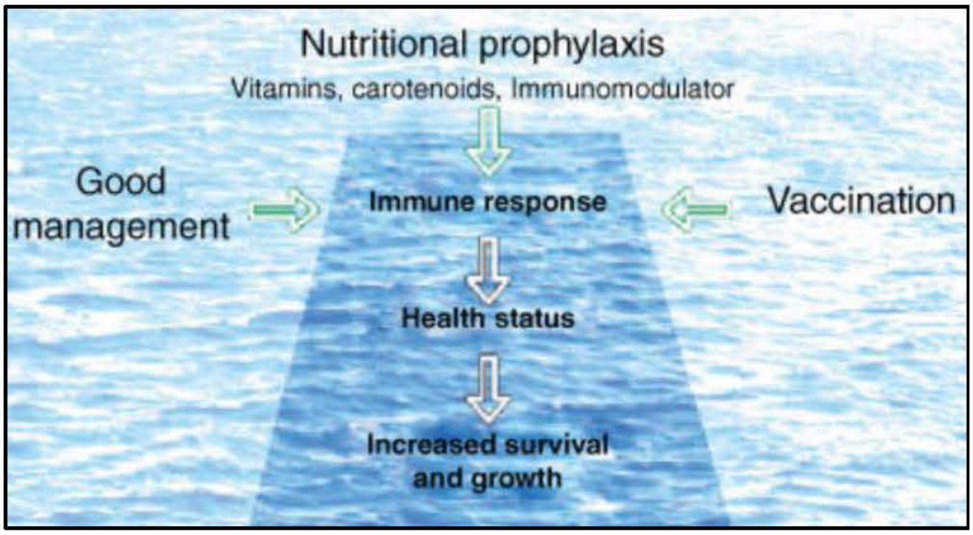
Persistent hyperglycemia can lead to various pathologies, generally related to liver damage and excessive glycogen deposition (NRC, 2011). Liver damage caused by excess dietary carbohydrates can lead to increased susceptibility to disease. Furthermore, Hemre et al. (1990, 1991) demonstrated that metabolic stress was indicated by increased plasma glucose and blood lactate in cod at starch levels that did not result in any growth depression.

In both carnivorous and omnivorous fish, excess carbohydrates in the diet causes metabolic stress and cellular changes. High glycogen deposits resulting from high carbohydrate intake caused changes in liver histology of both *Catla catla* (omnivorous) and rainbow trout (carnivorous) (Krogdahl et al., 2005).

Effects of Micronutrients on Fish Health

Micronutrients included in feeds in small amounts make large contributions to the health of fish. The term "nutritional prophylaxis" was introduced by Verlac Trichet et al. (2015). They explained that the immune system can be enhanced by the use of immunomodulators, such as vitamins, carotenoids, and other feed additives (Fig. 3), and that in combination with good management and vaccination, nutritional prophylaxis can increase survival rates in fish farms.

Figure 3. Benefits of nutritional prophylaxis in aquaculture (Verlac Trichet, 2015)



Vitamins

Vitamins are required nutrients for fish. A deficiency of any of the thirteen vitamins, if severe and prolonged, will create deficiency symptoms. Nine vitamins have been shown to positively affect the immune response and/or disease resistance of fish (Table 1). These vitamins are: C, E, A, D, thiamin, B6 (pyridoxine), folic acid, pantothenic acid, and myo-inositol (Shiau and Lin, 2015), Verlac Trichet (2015), and Izquierdo and Betancor (2015).

Vitamin C is the most studied vitamin in fish nutrition. It is involved in many physiological functions (Table 2), such as growth, reproduction, wound healing, collagen synthesis, and stress management (Verlhac Trichet et al., 2015. Vitamin C works with other antioxidants, such as vitamin E and selenium, to protect cells from oxidative damage. The functional importance of vitamin C in the immune response of fish has been extensively documented (Verlac Trichet et al., 2015). In a review (Verlhac Trichet et al., 2015) of the effects of vitamin C on health of fish, a positive effect on various immune response parameters was reported in 80 studies with 18 species. Elevated levels of vitamin C were reported to improve disease resistance in 8 studies with salmonids.

The requirement for vitamin C for grow-out diets for fish is an average of about 100 mg/kg diet. Most of the positive effects on the immune response were obtained within the range of about 400-1500 mg/kg diet, but many studies used levels of 3,000 – 4,000 mg/kg diet. However, it is difficult to compare concentrations of vitamin C between studies because of differences in bioavailability and resistance to oxidation.

Vitamin E is a generic term for ten homologous derivatives, with α-tocopherol having the highest *in vivo* antioxidant activity (Izquierdo and Betancor, 2015). Vitamin E is required for normal growth, reproduction, and maintenance of normal physiological functions and health of vertebrates (Evans and Bishop, 1922). Deficiency of vitamin E produces a wide variety of pathological conditions (Table 3), with muscular dystrophy being one of the most common in fish. Vitamin E is an essential nutrient for fish through its antioxidant activity that stabilizes tissue lipids, and its positive effects on disease resistance by modulating immune responses and preventing erythrocyte fragility.

Table 1. Deficiency symptoms and effects on immune system of Vitamins A, D, Thiamin, B6 (pyridoxine), folic acid, pantothenic acid, and myo-inositol (Shiau and Lin, 2015)

Vitamin	Species	Deficiency Symptoms	Effects on Immune System
A	Rainbow Trout, Common Carp, Atlantic Halibut, Grouper	Anemia, Twisted Gill Opercula, Hemorrhages In Fins And Around Eyes, **Poor Growth**, High Mortality, Anorexia, Pale Body Color, Erosion Of Caudal Peduncle	Limited In Trout. Significant Improvement In Japanese Flounder
D	Rainbow Trout, Channel Catfish	**Poor Growth**, Elevated Liver Lipid Content, Impaired Calcium Homeostasis, Lordosis	In Gilthead Sea Bream: Immunostimulant Effect Mostly On The Cellular Immune Parameters, Such As Phagocytic Activity And Respiratory Burst.
Thiamin	Channel Catfish, Salmon, Japanese Eel, Common Carp, Red Sea Bream, Turbot	Neurological Disorders With Varying Degrees Of Mortality	Improved Survival And Immune Response Parameters Of Jian Carp When Fed Up To 1.1 Mg/Kg Diet, But That Is Near The Requirement For Optimum Growth.
B6 (Pyridoxine)	Salmonids, Gilthead Sea Bream, Channel Catfish, Common Carp, Japanese Eel, Red Tilapia	Nervous Disorders (Such As Erratic Swimming, Hyperirritability, And Convulsions), **Poor Growth**, Anorexia, And Histopathological Changes In Liver, Kidney, And Intestinal Tissues	Studies On Jian Carp And Rohu Found Increased Immune Response Parameters When Fish Were Fed Diets Supplemented With Vitamin B6 At Levels Higher Than The Requirement For Growth. However, This Effect Was Not Found With Atlantic Salmon.
Pantothenic Acid	Salmonids, Channel Catfish, Red Sea Bream, Blue Tilapia, Lake Trout, Mexican Cichlid	Clubbed Gills (Gill Lamellar Hyperplasia) Anemia, High Mortality, Anorexia, Convulsions, **Poor Growth**, Hemorrhage, Sluggishness, Fatty Liver.	Boosted Pantothenic Acid Levels In Feed Fed To Jian Carp Led To Improved Immune Response And Lower Mortality When Fish Were Challenged With *A. Hydrophila*.
Folic Acid	Salmonids, Channel Catfish, Rohu	Anorexia, **Poor Growth**, Poor Fcr, Anemia, Increased Sensitivity To Bacterial Infection.	0.8 Mg Folic Acid/Kg Diet Was Sufficient For Maximizing Growth In Grouper And Was Also Sufficient To Produce Immune Responses.
Myo-Inositol	Rainbow Trout, Red Sea Bream, Japanese Eel, Japanese Parrotfish, Hybrid Tilapia, Olive Flounder	Poor Appetite, Anemia, **Poor Growth**, Fin Erosion, Dark Skin, Slow Gastric Emptying, Increased Lipid Deposition, Abnormal Lipid Metabolism.	Tripling Myo-Inositol Up To 687 Mg/Kg Diet In Feed Fed To Jian Carp Improved The Immune Response.

Requirements for vitamin E are species and age specific, ranging from 30 mg/kg for channel catfish to 300 mg/kg for common carp, and as much as 1200 mg/kg for gilthead sea bream (Izquierdo and Betancor, 2015). Vitamin E is considered an immune-stimulating factor in fish, with moderately increased vitamin E levels above those required for optimum growth resulting in health benefits. Vitamin E coupled with boosted levels of other antioxidants, such as vitamin C, have shown synergistic effects on disease and stress resistance, however Izquierdo and Betancor (2015) emphasized the need for further research with vitamin E, particularly in relation to the presence of other antioxidant nutrients, to better understand its effect on the immune system of fish.

Table 2. Deficiency symptoms of vitamin C and the health promotion effects of boosted inclusion levels of vitamin C over those required for optimum growth (Verlhac Trichet et al., 2015)

Vitamin C	Species	Deficiency Symptoms
	Many species studied	Reduced growth, scoliosis, lordosis, hemorrhage of internal tissues and fins, distorted gill filaments, fin erosion, anorexia, and increased mortality

Health Promoting Mode of Action	Health Promotion Effects
Collagen synthesis	Structural integrity of collagen-containing tissues
Antioxidant	Protection of cells from oxidative damage
Catecholamine synthesis	Stress response
Transformation of heavy metals into their reduced forms	Reduced toxicity of heavy metals

Table 3. Deficiency symptoms of vitamin E and the health promotion effects of boosted inclusion levels of vitamin E over those required for optimum growth (Izquierdo and Betancor, 2015)

Vitamin E	Species	Deficiency Symptoms
	Most fish Species specific	Muscular dystrophy Damage to liver, inhibition of maturation and reduction of egg hatching, no decrease in growth in some species, but even if no reduction in growth, increased erythrocyte fragility, reduced survival, increase in deformities

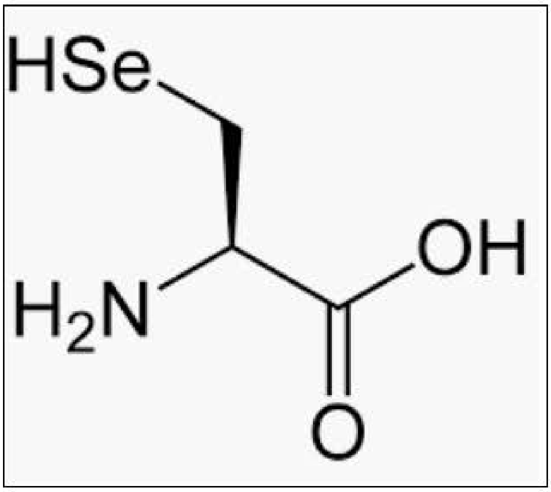
Health Promoting Mode of Action	Health Promotion Effects
Antioxidant	Improves stability of tissue lipids, especially cell membranes
Maintains immune response	Deficiency reduces immune response, normal levels allow good immune response, boosted levels boosts immune response (but not in all cases)
Maintains permeability of capillaries and heart muscle	Improves health of fish
Enables resistance response to stress	Reduced mortality

Minerals

Selenium works along with antioxidants, like vitamin E and C, to protect cells from oxidative damage and to protect polyunsaturated phospholipids from oxidative damage. Selenium is important in maintaining normal immune response, and is therefore a pivotal nutrient in disease resistance. However, excessive levels of selenium are toxic.

Selenocysteine (Fig. 4) is a component of glutathione peroxidase, which reduces lipid hydroperoxides to their corresponding alcohols. Selenium in the cytoplasm complements the antioxidant properties of vitamin E which is located in the cell membranes.

Figure 4. Structure of selenocysteine (Wikipedia)



Channel catfish fed diets with 0.40% phosphorus (P) exhibited increased growth and survival and higher levels of immune response parameters than when fed less P (Eya and Lovell, 1998). Clearly 0.40% P is a deficient level for channel catfish, as with many other species of fish, and had a negative effect on immunity.

Calcium in excess of about 2-3% of the diet can reduce the availability of zinc. Zinc deficiency symptoms in rainbow trout include: growth depression, high mortality, lens cataracts, erosion of fins and skin, and delayed wound healing.

Effects of Additives on Fish Health

Nonnutritional Immunostimulants (β-Glucans)

The function of ß-Glucans in fish diets is to activate the immune system, and they are one of the most commonly used immunostimulants (Gannam, 2015). Most immunostimulants are polysaccharides derived from cell walls of microorganisms and plants. Although there have been variable results in laboratory studies, they almost always provide some protection against opportunistic pathogens in disease challenges. However, results obtained in controlled laboratory experiments are not always achieved in production systems. ß-Glucans have not shown consistently positive effects.

Prebiotics

Prebiotics are defined as: non-digestible food ingredients that beneficially affect the host by selectively stimulating the growth of and/or activating the metabolism of one or a limited number of health promoting bacteria in the intestinal tract, thus improving the host's intestinal balance (Gibson and Roberfroid, 1995) and that confer benefits on host well-being and health (Gibson et al., 2004).

Prebiotics are mainly carbohydrates, short-chain oligosaccharides, with 3-10 sugar units, the target of which are the permanent colonizing (autochthonous) bacteria that competitively exclude pathogens (Gatlin, 2015). Prebiotics may reinforce the population of beneficial bacteria in the gut by acting as a food source, and thus indirectly decrease the potential for infection by pathogenic bacteria.

Promising results showing increases in immune responses and survival in a number of species have been achieved (Table 4). Improved nutrient utilization, resulting in increased nutrient digestibility, weight gain, and feed efficiency have also been observed in some trials with prebiotics.

Table 4. Results of trials with the prebiotics, Mannanoligosaccharides (MOS), Fructoligosaccharides (FOS), and GroBiotic-A.

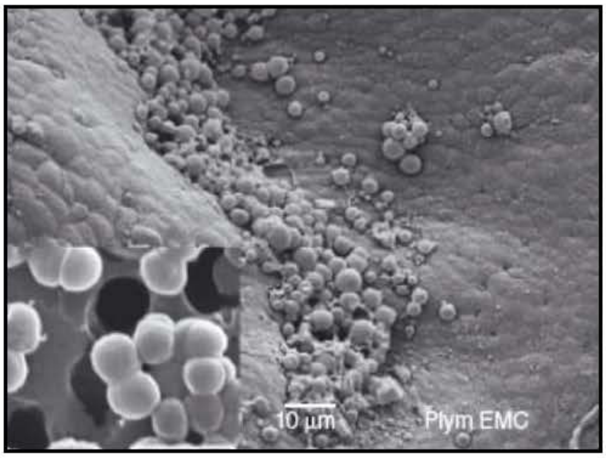
Oligosaccharides	Species	Results
Mannanoligosaccharides (MOS)	Rainbow trout	Increase in lysozyme activity, antibody titers, and survival (Staykov et al., 2007) Increased hemolytic and phagocytic activity (Rodrigues-Estrada et al., 2008)
Fructoligosaccharides (FOS)	Hybrid tilapia	Increased survival and non-specific immunity (He et al., 2003).
GroBiotic-A (a mixture of hydrolyzed brewer's yeast, dairy components, and fermented products)	Striped bass, Nile tilapia, golden shiner, rainbow trout, red drum	Improved immune response and increased survival. (Li and Gatlin, 2004, 2005) (Zheng et al. 2011) (Peredo 2011)

Probiotics

Probiotics are defined as live microbial adjuncts which have a beneficial effect on the host by modifying the host-associated microbial community and enhancing the host response towards disease (modified from Verschuere et al., 2000).

Modes of action of probiotic bacteria include: inhibiting or competing with pathogenic bacteria, producing mucous and antimicrobial peptides, preventing breaches in the mucosal barrier defense, and improving gut structure and nutrient utilization.

Figure 5. Colonization of the intestine of rainbow trout by feed-delivered microbials (Merrifield et al., 2010)



Candidates for probiotic species for aquaculture are mainly in the groups of lactic acid bacteria (LAB), bacillus bacteria, and yeasts (Table 5, Viswanath, 2015).

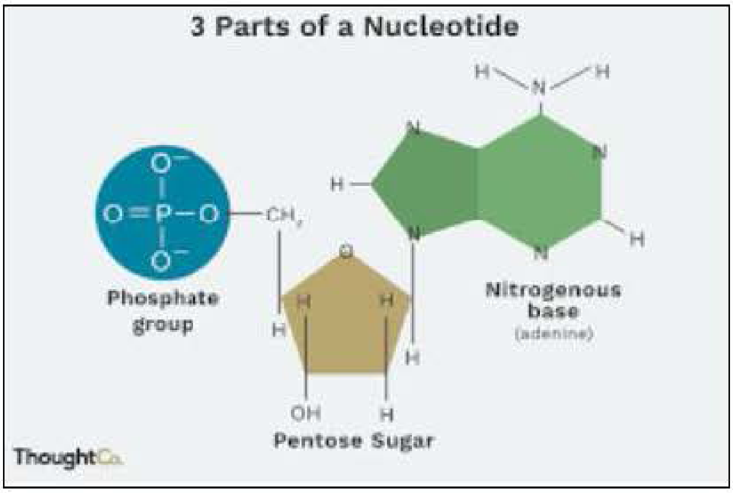
Table 5. Results of trials with probiotics used in tilapia, carp, and trout diets

Probiotic	Species	Results
Lactobacillus species (8 studies, In: Viswanath, 2015)	Nile tilapia, common carp, rainbow trout	Improved immune response, increased survival after challenge, improved gut morphology
Bacillus species (6 studies, In: Viswanath, 2015) In: Viswanath, 2015)	Nile tilapia, common carp, rainbow trout	Improved immune response, improved enzyme digestion activities
Saccharomyces species (5 studies, In: Viswanath, 2015)	Nile tilapia, common carp, rainbow trout	Improved immune response, improved enzyme digestion activities, increased survival of larval fish, improved microbiological parameters.

Nucleotides

Nucleotides are the precursors of the nucleic acids DNA and RNA. They supply the genetic information of an organism. Other nucleotides, ATP and GTP are important in energy storage. A nucleoside has the same sugar molecules and nitrogenous bases but lacks the phosphate molecule.

Figure 6. Three parts of a nucleotide (ThoughtCo.com)



Nucleotides occur in animal and plant feedstuffs. Examples are: fishmeal (1.4%), fish solubles (2.8%), yeast (0.9%), yeast extract (2.3%), and single-cell proteins (2.1%) (Devresse, 2000).

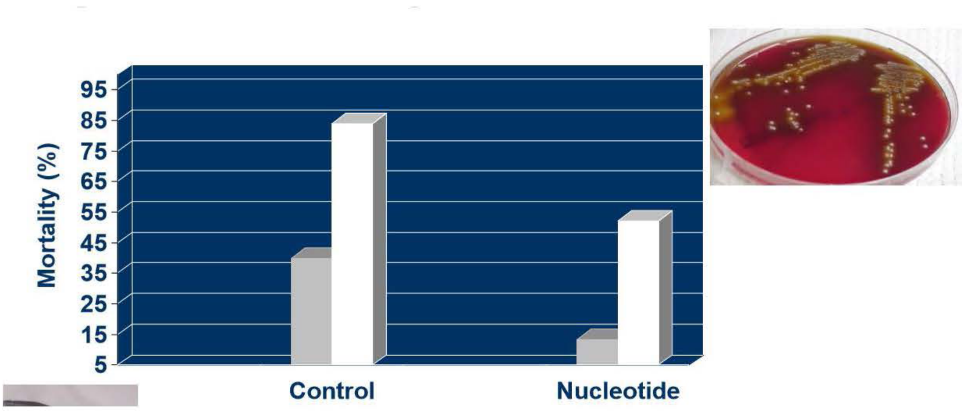
There has been much variation in the results from different studies conducted on the effects of nucleotides on disease resistance. This variation arose from the amounts of nucleotides present in the feed ingredients and the undisclosed amounts of individual nucleotides in commercial products.

Despite the complicating factors, some general conclusions can be drawn from research. Supplemental nucleotides have been shown to increase both the innate and adaptive components of the immune system in common carp, hybrid striped bass, olive flounder, rainbow trout, hybrid tilapia, Atlantic salmon and red drum (Li et al., 2015).

Survival was significantly increased by supplementing exogenous nucleotides to feeds fed to: Atlantic salmon, rainbow trout, common carp, hybrid striped bass, and olive flounder. It was also demonstrated that feeding supplemental nucleotides increased stress tolerance in Atlantic salmon, rainbow trout, and channel catfish.

It is better to run experiments with specific sets of nucleotides rather than use commercial products with undisclosed contents, such as the work done at Texas A&M by Li et al. (2004) who found significantly lower mortality of hybrid striped bass fed dietary oligonucleotides from yeast RNA in two separate experiments (Fig. 7).

Figure 7. Cumulative mortality of hybrid striped bass fed oligonucleotides from yeast RNA exposed to *S. iniae* (Li et al., 2004)



Organic Acids

Organic acids, such as acetic, butyric, citric, formic, lactic, malic, propionic, and sorbic acids, and their salts, have traditionally been used to reduce the risk of mold growth in feeds and more recently are being evaluated as to their efficacy in increasing digestibility of nutrients and increasing disease resistance (Lim et al., 2015).

Many studies have shown that inclusion of organic acids in feeds can increase the digestibility of phosphorus (NRC, 2011). Some studies that included organic acids in the experimental diets showed improved growth and survival after disease challenge, but in general, there has been significant variation in the results between studies using organic acids.

Luckstadt (2012) analyzed unpublished and published data from 18 trials with K-diformate (average concentration 0.41%) and tilapia. He found that on average: growth increased 5.6%, feed efficiency increased 4.5%, and the data on mortality was inconclusive due to high variation between conditions of the different trials.

Plant Extracts and Essential Oils

Whole plants or extracts have been shown to significantly improve immune response and disease resistance in many different species of fish (Jeney et al., 2015). Although the results are variable, plant extracts have been shown to be growth promotors and immunostimulants, with some degree of success achieved against bacteria, virus, and parasites. However, standardized and widespread use of plant extracts in aquaculture is complicated by a lack of knowledge of their active ingredients, limited availability of material, variable quality of raw material, unknown mechanisms of action, and unavailable toxicological tests and controlled clinical trials.

In their chapter on plant extracts, Jeney et al. (2015) mention more than 50 plant species and 16 species of fish.

Sutili et al. 2017 listed 20 sources of essential oils that had positive effects on growth, immune response, antioxidant activity, and nutrient utilization in a number of species of fish.
Stability of essential oils is a concern as some can be lost through volatilization, conversion, or

degradation during feed manufacture and storage.

Conclusions

It is well established that deficiencies of macronutrients and micronutrients in diets will negatively affect growth, feed efficiency, immune responses, and disease resistance of fish. Feeding complete, well-balanced diets to farmed fish will allow fish to exhibit their full potential for disease resistance. Some nutrients provided at levels above those required for optimum growth can increase immune responses and disease resistance in fish. Examples of those nutrients were reviewed in this paper. In addition, a number of non-nutritional feed additives have also been shown to improve immune competence in fish. Although there are many studies involving the health benefits of a wide variety of additives, significant decreases of fish mortality under practical commercial conditions are not always achieved.

The field of nutritional prophylaxis in aquaculture draws intense interest due to its potential to reduce economic losses due to disease without the use of antibiotics and other chemical treatments that are not viewed as safe alternatives. However, much research is still needed to document which nutrients and additives are most cost effective in reducing mortality of farm-raised fish.

About the Author

Mark Newman has worked for more than 40 years in the fields of aquaculture, aquaculture nutrition, the manufacture of aquafeeds, and fisheries biology. He worked for a major U.S. feed manufacturer in the U.S. and Ecuador for 20 years in the areas of nutrition, quality assurance, management, and technical support. He has commercially farmed marine shrimp and has conducted nutritional research with tilapia, Pacific salmon, freshwater prawns, a variety of marine fish, and marine shrimp. Presently he is an aquaculture nutrition and feedmill consultant providing technical assistance to feedmill companies in many parts of the world, including: Latin America, South East Asia, Pakistan, Bangladesh, India, and Egypt.

Soy In Aquaculture Program

This technical paper was created through the USSEC Soy In Aquaculture (SIA) program and the USSEC Southeast Asian Regional Program. USSEC works with target audiences in Southeast Asia and globally to show the utility and benefits of using United States soybean products in aquaculture diets.

The SIA program replaces the Managed Aquaculture Marketing and Research Program (the AquaSoy Initiative, funded and supported by the United Soybean Board and American Soybean Association) which was designed to remove the barrier to soybean meal use in diets fed to aquaculture species.

The objective of the SIA is to optimize soy product use in aquaculture diets and to create a preference for U.S. soy products in particular, including but not limited to U.S. soybean meal, soybean oil, soybean lecithin, and "advanced soy proteins" such as fermented soy and soybean protein concentrate.

This paper follows the tradition of USSEC to provide useful technical materials to target audiences in the aquaculture industry.

For more information on soybean use in aquaculture and to view additional technical papers, please visit the Soy-In-Aquaculture website at www.soyaqua.org.

References

Calder, P.C., 2007, "n-3 fatty acids, inflammation and immunity: new mechanisms to explain old actions," Proceedings of the Nutrition Society 72(3), pp. 326-336.

Castell, J.D., Sinnhuber, R.O., Wales, J.H., Lee. J.D., 1972, "Essential fatty acids in the diet of rainbow trout: Lipid metabolism and fatty acid composition," J. Nutr., 102, pp. 77-86.

Das, U.N., 2006, "Essential fatty acids – a review," Curr. Pharm. Biotechno., 7, pp. 467-482.

Evans, H.M., Bishop. K.S., 1922, "On the existance of a hitherto unrecognized dietary factor essential for reproduction," Science, 56, pp. 649-651.

Eya, J.C., Lovell. R.T., 1998, "Effects of dietary phosphorus on resistance on channel catfish to *Edwardsiella ictalurid* challenge," Journal of Aquatic Animal Health, 10, pp. 28-34.

Gannam, A.L., 2015, "ß-Glucans. In: Dietary Nutrients, Additives, and Fish Health," (C-S Lee, C. Lim, D. Gatlin, and C Webster, eds.) Wiley-Blackwell, John Wiley & Sons, Inc., New Jersey, pp. 111-124.

Gatlin, D.M., 2015, "Prebiotics. In: Dietary Nutrients, Additives, and Fish Health," (C-S Lee, C. Lim, D. Gatlin, and C Webster, eds.) Wiley-Blackwell, John Wiley & Sons, Inc., New Jersey, pp. 271-281.

Gibson, G.R., Roberfroid, M.B., 1995, "Dietary modulation of the human colonic microbiota: introducing the concept of prebiotics," The Journal of Nutrition, 125, pp. 1401-1412.

Gibson, G.R., Probert, H.M., Van Loo, J., Rastall, R.A., Roberfroid, M.B., 2004, "Dietary modification of the human colonic microbiota: updating the concept of prebiotics," Nutrition Research Reviews, 17, pp. 259-275.

Ghittino, P., 1989, "Nutrition and Fish Diseases, In: Fish Nutrition," 2nd Edition, (J.E. Halver, ed.) Academic Press, Inc., New York. pp. 681-713.

He, S., Xu, G., Wu, Y., Weng, H., Xie, H., 2003, "Effects of IMO and FOS on the growth performance and non-specific immunity in hybrid tilapia," Chinese Feed 23, pp. 14-15 (in Chinese).

Hemre, G.-I, Lie, O., Lambersten, G., Sundby. A., 1990, "Dietary carbohydrate utilization in cod (*Gadus morhua*): Hormonal response of insulin, glucagon and glucagons-like-peptide to diet and starvation," Comparative Biochemistry and Physiology 97, pp. 41-44.

Hemre, G.-I., Lambertsen, G., Lie, O., 1991, "The effect of dietary carbohydrate on the stress response in cod (*Gadus morhua*)," Aquaculture 95, pp. 319-328.

Izquierdo, M., Betancor. M., 2015, "Vitamin E. In: Dietary Nutrients, Additives, and Fish Health," (C-S Lee, C. Lim, D. Gatlin, and C Webster, eds.) Wiley-Blackwell, John Wiley & Sons, Inc., New Jersey, pp. 172-193.

Jeney, G., De Wet, L., Jeney, Z., Yin. G., 2015, "Plant Extracts. In: Dietary Nutrients, Additives, and Fish Health," (C-S Lee, C. Lim, D. Gatlin, and C Webster, eds.) Wiley-Blackwell, John Wiley & Sons, Inc., New Jersey, pp. 321-332.

Kiron, et al. 1993. "Dietary nutrient dependent variations on natural-killer activity of the leucocytes of rainbow trout," V. Kiron, A. Gunji, N. Okamoto, S. Satoh, Y. Ikeda, and T. Watanable, Gyobyo Kenkyu, 28(2), pp. 71-76.

Kiron, V., Watanabe, T., Fukuda, H., Okamoto, N., Takeuchi, T., 1995, "Protein nutrition and defence mechanisms in rainbow trout *Oncorhynchus mykiss,*" Comparative Biochemistry and Physiology Part A, Physiology 111 (3), pp. 351-359.

Krogdahl, A., Hemre, G.I., Mommsen, T.P., 2005, "Carbohydrates in fish nutrition: digestion and absorption in postlarval stages," Aquaculture Nutrition, 11, pp. 103-122.

Lee, C-S., Lim, C., Gatlin, D., Webster, C., 2015, "Dietary Nutrients, Additives, and Fish Health," (C-S Lee, C. Lim, D. Gatlin, and C Webster, eds.) Wiley-Blackwell, John Wiley & Sons, Inc., New Jersey.

Legate et al. 2001, "Glucose tolerance and peripheral glucose utilization in three fish species," Legate, N.J., A. Bonen, and T.W. Moon., Gen. Comp. Endocr, 122, pp. 48-59.

Li, P., Gatlin, III. D.M., 2004, "Dietary brewers yeast and the prebiotic GroBiotic AE influence growth performance, immune responses and resistance of hybrid striped bass (*Morone chrysops x M. saxatilis*) to *Streptococcus iniae* infection," Aquaculture, 231, pp. 445-456.

Li, P., Gatlin, III. D.M., 2005, "Evaluation of the prebiotic Grobiotic-A and brewer's yeast as dietary supplements for sub-adult hybrid striped bass (*Morone chrysops x M. saxatilis*) challenged in situ with *Mycobacterium marinum*," Aquaculture, 248, pp. 197-205.

Li, P., Lewis, D.H., Gatlin III. D.M., 2004, "Dietary oligonucleotides from yeast RNA influence immune responses and resistance of hybrid striped bass (*Morone chrysops x M. saxatilis*) to *Streptococcus iniae,*" Fish and Shellfish Immunology, 16, pp. 561-569.

Li, P., Zhao, J., Gatlin III. D., 2015, "Nucleotides. In: Dietary Nutrients, Additives, and Fish Health," (C-S Lee, C. Lim, D. Gatlin, and C Webster, eds.) Wiley-Blackwell, John Wiley & Sons, Inc., New Jersey, pp. 249-270.

Lim, C., Luckstadt, C., Webster, C.D., Kesius, P., 2015, "Organic acids and their salts. In: Dietary Nutrients, Additives, and Fish Health," (C-S Lee, C. Lim, D. Gatlin, and C Webster, eds.) Wiley-Blackwell, John Wiley & Sons, Inc., New Jersey, pp. 304-320.

Lovell, T., 1989, "Nutrition and Feeding of Fish," AVI, an imprint of Van Nostrand Reinhold. New York, pp. 280.

Luckstadt, C., 2012, "Effects of dietary potassium diformate on juvenile tilapia – A performance analysis," Book of Abstracts, XV International Symposium on Fish Nutrition and Feeding, June 4-7, 2012, Molde, Norway, pp. 232.

Merrifield, D.L., Dimitroglou, A., Foey, A, Davies, S.J., 2010, "The current status and future focus of probiotic and prebiotic applications for salmonids," Aquaculture Research, 41, pp. 1268-1272.

National Research Council, 2011, "Nutrient Requirements of Fish and Shrimp," The National Academic Press, Washington, D.C., pp. 376.

O'Keefe, T., President, Aqua-Food Technologies, Inc.

Peredo, A.M., 2011, "Evaluation of the dairy/yeast prebiotic, GroBiotic-A in the diet of juvenile Nile tilapia, *Oreochromis niloticus*)," Master's Thesis, Texas A&M University, College Station, Texas, USA.

Roberts, R.J, Bullock. A.M., 1989, "Nutritional Pathology, In: Fish Nutrition," 2nd Edition, (J.E. Halver, ed), Academic Press, Inc., New York. pp. 423-473.

Shiau, S-Y., Lin, Y-H., 2015, "Vitamins (Excluding C and E). In: Dietary Nutrients, Additives, and Fish Health," (C-S Lee, C. Lim, D. Gatlin, and C Webster, eds.) Wiley-Blackwell, John Wiley & Sons, Inc., New Jersey, pp. 125-150.

Snieszko, S.F., 1972, "In: Fish Nutrition," (J.E. Halver ed.) Academic Press, New York. pp. 422-427.

Sutili, F.J., Gatlin III, D.M., Heinzmann, B.M., Baldisserotto, B., 2017, "Plant essential oils as fish diet additives: Benefits on fish health and stability in feed," Reviews in Aquaculture, pp. 1-11.

Verlac Trichet, V., 2010, "Nutrition and immunity: an update," Aquaculture Research, 41, pp. 356-372.

Verlac Trichet, V., Santigosa, E., Cochin, E., Gabaudan. J., 2015, "The effect of vitamin C on fish health. In: Dietary Nutrients, Additives, and Fish Health," (C-S Lee, C. Lim, D. Gatlin, and C Webster, eds.) Wiley-Blackwell. John Wiley & Sons, Inc., New Jersey, pp. 151-171.

Viswanath, K., 2015, "Gastrointestinal microorganisms of fish and probiotics. In: Dietary Nutrients, Additives, and Fish Health," (C-S Lee, C. Lim, D. Gatlin, and C Webster, eds.) Wiley-Blackwell, John Wiley & Sons, Inc., New Jersey, pp. 282-303.

Zheng, Z.L., Wang, K.Y., Gatlin, III, D.M., Ye, J.M., 2011, "Evaluation of the ability of GroBiotic-A to enhance growth, muscle composition, immune responses, and resistance against *Aeromonas hydrophila* in Nile tilapia, *Oreochromis niloticus*," Journal of the World Aquaculture Society, 42, pp. 549-556.

U.S. Soybean Export Council Headquarters

16305 Swingley Ridge Road, Suite 200
Chesterfield, MO 63017, USA
TEL: +1 636 449 6400
FAX: +1 636 449 1292
www.ussec.org

USSEC INTERNATIONAL OFFICES

USSEC AMERICAS
Carlos Salinas
REGIONAL DIRECTOR – AMERICAS (AM)
U.S. Soybean Export Council
16305 Swingley Ridge Road, Suite 200
Chesterfield, MO 63017-USA
CSalinas@ussec.org
TEL: +52 331 057 9900

USSEC GREATER CHINA
Xiaoping Zhang
REGIONAL DIRECTOR - GREATER CHINA
U.S. Soybean Export Council
Suite 1016
China World Office #1
China World Trade Center
No. 1 Jianguomenwai Avenue
Beijing 100004
People's Republic of China
XPZhang@ussec.org
TEL: +86 106 505 1830
FAX: +86 106 505 2201

USSEC NORTH ASIA
Rosalind Leeck
SENIOR DIRECTOR - MARKET ACCESS AND REGIONAL DIRECTOR - NORTH ASIA
16305 Swingley Ridge Road, Suite 200
Chesterfield, MO 63017
RLeeck@ussec.org
TEL: +1 314 304 7014
FAX: +1 636 449 1292

USSEC SOUTH ASIA
Kevin Roepke
REGIONAL DIRECTOR - SOUTH ASIA
16305 Swingley Ridge Road, Suite 200
Chesterfield, MO 63017-USA
KRoepke@ussec.org
TEL: +1 314 703 1805

USSEC GREATER EUROPE, MIDDLE EAST/NORTH AFRICA
Brent Babb
REGIONAL DIRECTOR - GREATER EUROPE AND MIDDLE EAST/NORTH AFRICA (MENA)
16305 Swingley Ridge Road, Suite 200
Chesterfield, MO 63017
BBabb@ussec.org
TEL: +1 636 449 6020
FAX: +1 636 449 1292

USSEC SOUTHEAST ASIA AND OCEANIA
Timothy Loh
REGIONAL DIRECTOR - SOUTHEAST ASIA
U.S. Soybean Export Council
541 Orchard Road
#11-03 Liat Towers
Republic of Singapore 238881
TLoh@ussec.org
TEL: +65 6737 6233
FAX: +65 737 5849