The impact of nutrition on fish development, growth and health

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Abstract- This study reviews the effect of nutrition on fish development, growth and health. The need for sound nutrition and adequate feeding for fish cultured in captivity cannot be over emphasized. If there is no utilizable feed intake by the fish, there can be no growth and death eventually results. Diet contributes toward increased growth and weight gain. Growth is due mainly to protein tissues and increase in body carcass. Lipids are important source of energy and fatty acids that are essential for normal growth, survival of fish, fish development and flesh quality. Lipids are important in the structure of biological membrane at both the cellular and sublevel. Vitamins are used for building the body mass of the fish and also affect the skin. Proper nutrition promotes normal growth, good flesh quality and sustains health of fish. Fish fry/fingerlings are especially sensitive to dietary nutrient supply, compared to juveniles. A slight imbalance or maladjusted supply form in some nutrients such as amino acids, fatty acids or vitamins will impair development and quality of the fish. Same diet could have a different impact on morphogenesis, if given at different periods to fish. Nutritional disorder weakens the flesh of the fish and lead to disease. Hyper vitaminosis A delayed development, reducing the number of vertebrae and the quality of the fish. Fish could constitute an interesting model for studies on the impact of nutrition on higher vertebrate development, since very precocious stages are accessible for nutritional experiment.

Index Terms- fish, morphogenesis, growth, muscle differentiation, diet, health

I. Introduction

The need for sound nutrition and adequate feeding for fish cultured in captivity has increased over the last few decades largely due to the increase in demand for fish in the global market. Fish nutrition has advanced dramatically in recent years with the development of new, balanced commercial diets that promote optimal fish growth and health. The development of new species-specific diet formulations supports the aquaculture (fish farming) industry as it expands to satisfy increasing demand for affordable, safe, and high-quality fish and seafood products. If there is no utilizable feed intake by the fish, there can be no growth and death eventually results.

Proper nutrition has long been recognized as a critical factor in promoting normal growth, thus generating good body composition/flesh quality and sustaining health of fish. As such, nutritious diets and appropriate feeding regimes play critical roles in intensive aquaculture. The objective of feeding fish therefore, is to provide the nutritional requirements for good health, optimum growth, optimum yield and minimum waste, within reasonable cost, so as to optimize profits (1). In recent years, heightened attention has been given to the development of nutritional strategies that positively influence immunity and disease resistance of cultured organisms to reduce disease-related economic losses. An understanding of how to nurture and/or modulate the different components of the immune system is crucial for the prevention and control of diseases in animal husbandry.

The six classes of nutrients (water, proteins and other nitrogenous compounds, lipids, carbohydrates, minerals and vitamins) are essential for growth, reproduction and maintenance of health. The macronutrients (protein, lipids and carbohydrates) provide bulk energy for fish metabolic system to function. They are also used to build and repair tissues, regulate body processes and are converted and used for energy. The micronutrients, which include the macro-minerals (calcium, phosphorous, magnesium, chloride, sodium, potassium, sulphur), and the micro-minerals (also known as trace metals) include cobalt, chromium, copper, iodine, iron, manganese, selenium, and zinc. These provide the necessary cofactors for metabolism to be carried out. Both types of nutrients can be acquired from the environment, but in order to accelerate growth, these must be consciously provided in formulated diets.

Fish nutrition has advanced dramatically in recent years with the development of new balanced commercial diet that promote optimal fish growth and health. The development of new species-specific diet formulation supports the aquaculture industry, as it expands to satisfy increasing demand for affordable, safe and high quality fish and seafood products. Artificial diets manufactured from various feedstuffs are the primary source of nutrition in intensive aquaculture. Prepared diet, not only provides the essential nutrients that are required for normal physiology function, but also may serves as medium by which fish are exposed to other components, which may affect their health, either positively or negatively. A deficiency of any nutrient, if served enough, can adversely affect fish health, either directly by impairing metabolic function, or indirectly by making the fish more susceptible to opportunistic disease-causing agents. Proper nutrition is thus a necessity for good growth, top flesh quality and health of fish. Good and healthy fish commands high market value, the ultimate purpose of fish husbandry. It is in realization of this value that this paper reviews the impact of nutrition on fish larvae development, growth and health

II. LARVAL DEVELOPMENT

Fish fry/fingerlings are especially sensitive to dietary nutrient supply, compared to juveniles. A slight imbalance or maladjusted supply form in some nutrients such as amino acids, fatty acids or vitamins will impair development and quality of the fish (Fig. 1). The nutrients are used to build body mass, but also act as modulators of genes involved in organogenesis and skeletal development (2,3,4), which need to be better investigated in fish. From this point of view, fish could also constitute an interesting model for studies on the impact of nutrition on higher vertebrate development, since very precocious stages are accessible for nutritional experiment.

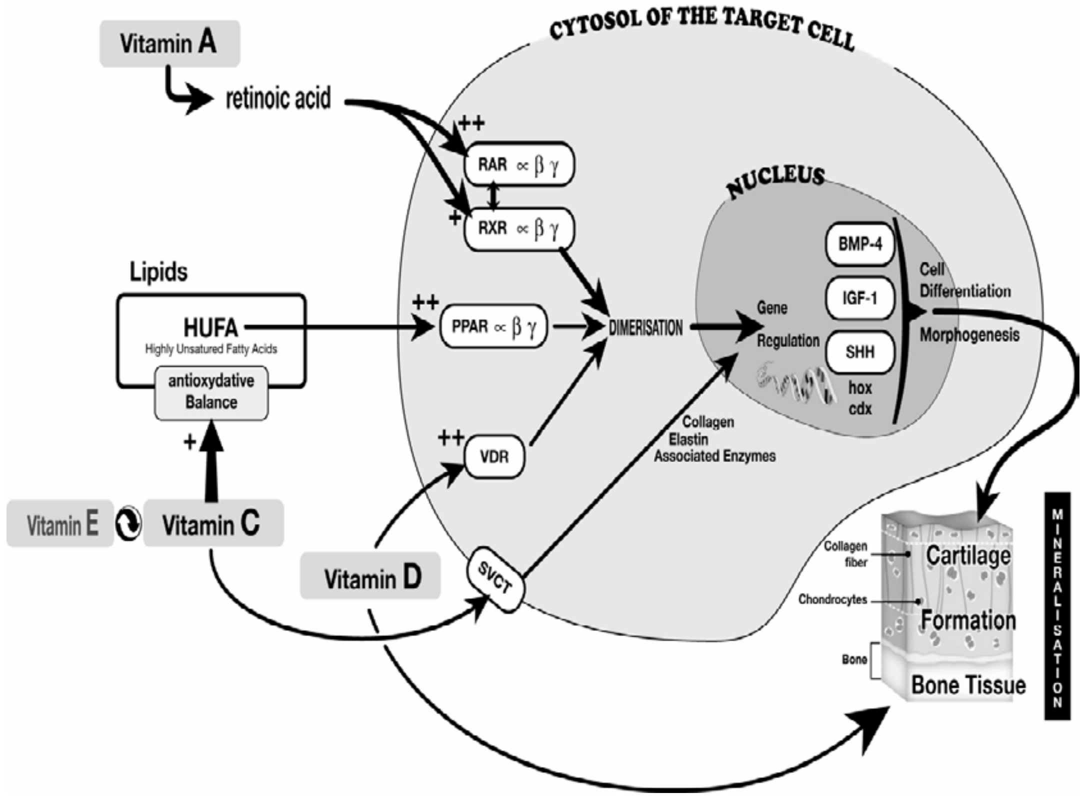

Fig.1: Possible impact of dietary nutrients on some metabolic pathways controlling development morphogenesis and quality of marine fish (3).

RAR: Retinoic Acid Receptor, RXR: Retinoid X Receptor, PPAR: Peroxisome Proliferator Activated Receptor, VDR: Vitamin D Receptor, SVCT: Vitamin C transporter system, BMP: gene coding for Bone Morphogenetic Protein, IGF: gene coding for Insulin-like Growth Factor; SHH: sonic hedgehog gene, hox: hox genes, cdx: caudal-related homeobox genes

Events at critical period of early life could influence long-term outcome, development of a somatic structure resulting from a stimulus or injury. These physiological responses reflect a biological mechanism which is turned irreversibly "on" or "off" only once during an individual's lifetime in response to condition prevailing at some critical stage. The term of programming is often used to describe this biological mechanism (5). A key challenge is to identify stressors that are capable of permanently altering organ development and function, and also stages of development of greatest vulnerability. The effect of early nutrition on finfish larvae and juvenile development has been mainly studied with the aim to reduce fish morphological abnormalities that adversely affect the image and profits of fish culture. However, the possibility of orientating specific metabolic pathways or functions in juvenile fish, for example, to facilitate the use of substitutes to fish meal and oil and to promote sustainability in fish culture, has just begun to be considered in fish quality.

Effects of Vitamins on Larvae Development

Accurate data concerning vitamin requirements in fish are very recent. Indeed, up to the last decade, these requirements were studied using live prey enrichment, which gave some interesting indications, but non comprehensive data (6). Deficiencies in vitamins can cause stunted growth, loss of appetite, cloudy eyes, weakness or tumors in fish. Ascorbic acid would reduce the incidence of opercula abnormalities in milkfish *Chanos chanos* larvae (7). These abnormalities associated with distortion of gill filament cartilage are characteristic of scorbutic fish (8) and is the result of decalcification (6).

Compound diets are usually formulated with high vitamin levels, in order to avoid any possible vitamin deficiency. (9) and (10) incorporated 240mg equivalent vitamin C in larval diet, i.e.

8 times more than for juveniles. This high vitamin requirement was supported by an experiment conducted with purified compound diet incorporating a vitamin C gradient which indicated that the dietary requirements of carp larvae is between 45 mg ascorbic acid equivalent per Kg of diet (value to obtain optimal growth and survival) and 350mg (value to obtain vitamin C maximum concentration in tissues) (11). Moreover, (12) showed that larvae are more sensitive to vitamin C deficiency than juveniles.

More recently, in relation to skeletal abnormalities affecting fry production in hatcheries, attention has been paid to vitamin A and its active metabolite, retinoic acid. Taking account of growth, survival and development of digestive function in intestine, the optimal level was determined at 30 mg all-*trans* retinol/kg diet dry matter. Higher or lower levels of vitamin A induced poorer growth and survival. Interestingly, a linear relationship between dietary vitamin A and skeletal malformation incidence in fish was demonstrated.

Skeletal malformations can also be induced by an inadequate dietary vitamin D3 level. However, some other study focused on the effect of vitamin D3 on pigmentation, a default in pigmentation being a major problem for flat fish hatcheries. (13) showed that an excess in vitamin D3 (20 000 IU /100g diet) induced hypermelanosis in the Japanese flounder, especially on the blind side of the fish. Beside its role in calcium homeostasis and bone formation, (14) and (14) reported that this vitamin acts on cell proliferation and differentiation. Moreover, the skin is a target organ of this vitamin, which has been shown to be involved in stimulation of melanogenesis in human melanocytes (16). Nutritional deficiencies can impair the utilization of other nutrients, weaken the health of the fish, and lead to disease

Morphogenesis

Morphogenesis is a process that implies a precise spatial and temporal expression of some specific genes, like Hox genes, that are major actors in body patterning (limbs, vertebrae, craniofacial structures) (17). These genes may be then particularly sensitive to dietary modulations of some transcription factors during these temporal windows of development. Therefore, same diet could have a different impact on morphogenesis, if given at different periods to fish. (18) have fed larvae of Japanese flounder with Artemia containing high concentrations of vitamin A, at different developmental stages. They reported that vertebral deformities occurred in fish, when exposed to these high vitamin A doses during day 25-27 post-hatching period that corresponds to the notochord segmentation. After this period, the exposure of larvae to high dietary vitamin A levels did not induce any malformations. This study clearly showed how the timing of vitamin A intake influenced the risk of appearance of deformities in vertebrae.

(19) demonstrated that inadequate vitamin A or high HUFA levels in diets highly affected sea bass larvae morphogenesis, when given earlier than 18 dph (day post hatching). They reported that hyper vitaminosis A delayed development, reducing the number of vertebrae and the quality of the fish.

Muscle Development

Nutrition status has profound effects on the growth and development of somatic tissues, particularly the skeletal muscle. Muscle development, during larval period, is characterized by hypertrophy (increase of muscle diameters) and by hyperplasia (recruitment of new muscle fibers) from undifferentiated myoblasts. (20) reported that the proliferation and differentiation of these cells lead to the formation of new fibers, a process regulated by several myogenic regulatory factors that can also be influenced by environmental and nutritional parameters. Myostatin is known to regulate muscle growth and development, by inhibiting specifically myoblast proliferation via cell-cycle arrest (21). However, the effect of nutrition has been mostly studied comparing extreme nutritional conditions, i.e. fasting/feeding, which do not allow to understand how to orientate (and improve) further muscle development. Some dietary nutrients, like ascorbic acid, could be worth more studies. Indeed, this nutrient is a precursor of collagen and could have a crucial role for muscle development in fish, particularly in the white myotomal muscle which exhibited certain plasticity during larval period (22).

III. FISH GROWTH

Growth is particularly high during larval stages, and growth is mainly related to muscle protein deposition. Several workers have reported that feeding C*larias gariepinus* fingerlings with various formulated diets contributed toward increased growth (23, 24) compared with the initial fish (Fig. 2), and concluded that the weight gain were due mainly to protein tissues and increase in body carcass (flesh) protein.

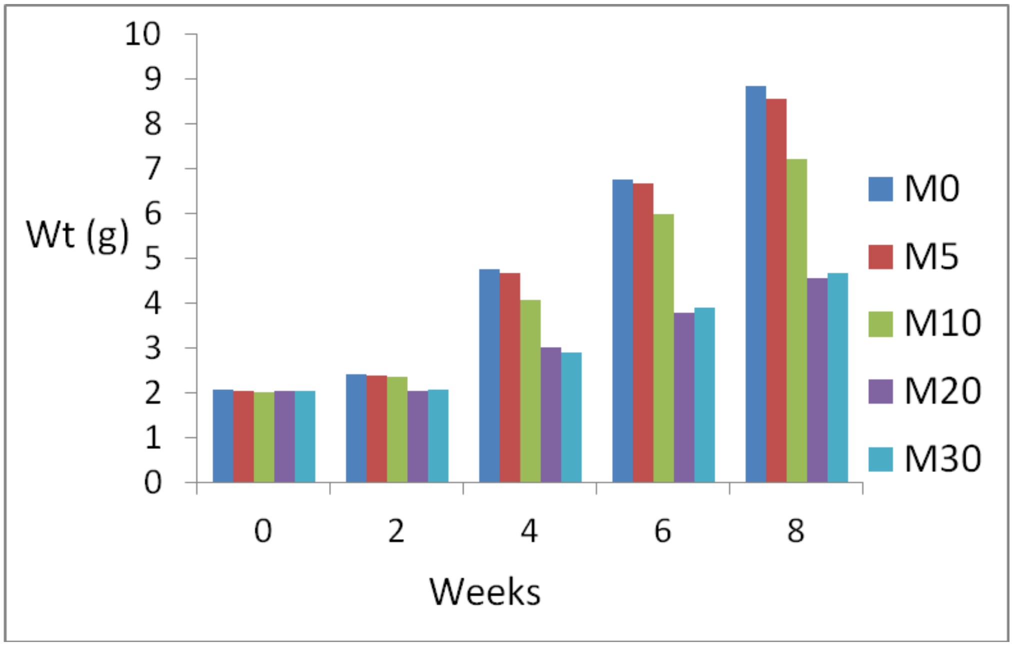

Fig. 2: The growth performance of *C. gariepinus* fed moringa based diets (23).

However, total requirement in protein has been poorly studied. It was generally supposed to be higher than in juveniles (25) and (26) showed that diet containing 50 to 60% protein induced better growth than a similar isocaloric diet containing only 30 and 40% protein respectively. These proteins were supplied as fish meal, which is considered as the protein source providing the best amino acid profile for fish requirement. This was buttressed by (27,23,28) and (28) who indicated severally that the use of alternative fishmeal replacers could not effectively meet the nutritional requirement of fish for growth, health and development. As good as fishmeal based diet was, (26) maintained however, that in this experiment, it appeared that both mRNA coding for trypsin and trypsin activity were not regulated by dietary fish meal concentration at day 18. The modulation of trypsin activity by dietary fish meal occurred only from day 35. The regulation of this enzyme, as other digestive enzymes in fish larvae, is age dependent. In the same way, it was showed that native protein are better absorbed in 31 day old halibut rather than in 25 day old larvae (29).

Fish larval requirements in indispensable amino acids, their changes during ontogenesis and the differences between species, have been extensively studied (30). Recent studies have demonstrated that the conventional live prey sequence, rotifer and artemia, would supply some indispensable amino acids in deficient or limiting amount for growth. Indeed, histidine appears to be the limiting amino acid at two day post-hatching in the white sea bream (*Diplodus sargus*), threonine at day 12 post-hatching, then cysteine and methionine were considered as limiting later in the development (31). The enrichment of live prey with amino acids is hazardous, and it will be more rational to formulate compound diets with balanced amino acid profile. As demonstrated above, fish meal though having a convenient amino acid profile, is not the best supply form when provided alone. But peptides, in synthetic form, as recommended by (32), could be added in diet to provide a convenient concentration in the different amino acids.

Contributions of Fatty Acids and Lipids

Lipid constitutes, along with free amino acids, the most important energy reserve in fish embryos (33). Studies conducted on different species agreed that larval development requires high dietary lipid level (18% lipid/dry matter in sea bream), 25% for *Paralichthys olivaceus*, 25 to 30% in sea bass (34). It is assumed that young larvae require high energy (20 KJ/Kg of diet). But the effect depends on the nature of the lipids. Diets containing 26% lipid can lead to very poor growth and low survival, if lipids are mainly neutral lipid, while a similar diet containing 14% neutral lipid and 12% phospholipid induce high growth and survival in sea bass larvae (35). This growth depressing effect of high dietary neutral lipid levels has been reported in different marine fish species (36). Indeed, high neutral lipid levels result in an accumulation of large lipid droplet in the enterocytes, mainly in anterior intestine. This accumulation has not been described as pathological, but reflects a limited capacity for assembling triglycerides with apolipoprotein, necessary for the transfer of triglycerides into the general circulation. In the same way, lipase is not finely regulated by the dietary neutral lipids, maximal activity level in level being reached with 20% dietary lipid. So the high lipid level requirement in fish does not correspond only to a high energy requirement, but also to a specific requirement in some fatty acids and phospholipids.

About 15-30% of fish diets are lipids, and the increase of dietary lipids contributes to reducing diet costs, by diminishing protein content (37), and maximizing protein retention and fish performance (38). An increase of lipids in the diet can however lead to higher body fat deposition (39,40), and induce metabolic alterations, including fatty (41), abnormal oxidative status (42), impairment of nutritional value and transformation yield, or affect organoleptic and physical properties of the fillets (43,44) which may reduce its commercial value (45). So it is fundamental knowing the optimal levels of dietary lipids that promotes maximum efficiency of fish growth, development and flesh quality (46).

The nutritionally active components of dietary lipids are fatty acids (FA). Fish and mammals appear to be unable to synthesize fatty acids that are unsaturated in the w-3 or w-6 positions, unless a suitable precursor is supplied in the diet. Generally, there are only two essential fatty acids. These are linoleic and α-linolenic acids that can be elongated and desaturated by the animals to the functional FA. Fatty acids can be: a) saturated fatty acids (SFA, no double bonds), b) polyunsaturated fatty acids (PUFA, >2 double bonds), or c) highly unsaturated fatty acids (HUFA). However, marine fish can only meet their FA requirements with highly unsaturated fatty acids (HUFAs) of the n-3 series : eicosapentaenoic (EPA; 20:5(n-3)) and docosahexaenoic (DHA; 22:6(n-3)), as they lack or have a very low activity of 5-desaturase, thus preventing the elongation and desaturation of the precursor α-linolenic acid (47,48). These two high unsaturated fatty acids (HUFAs) play diverse roles in cells, controlling and regulating growth performance, survival, stress resistance, cell membrane fluidity, immune function, nervous system development, vision and pigmentation (49).

It is now well known that HUFA has a major role in fish development. (50) considered the HUFA content in fish eggs and recommended an optimal level of total HUFA, (mainly eicosapentaenoic acid (EPA) and docohexaenoic acid (DHA), of around 3% of dry weight for larvae diet. This recommendation was supported by experimental data, showing an optimal value of 2.5% EPA and DHA for sea bass larvae. But this amount is inefficient to promote growth in sea bass larvae, and can even lead to total mortality (51). On the contrary, the same quantity of EPA+DHA supplied as phospholipids induces good growth and survival. Growth and survival are depressed when EPA+DHA level fall short of this optimal value. Diets containing 1% and 5% EPA+DHA induced poor development in sea bass fish. High prevalence of skeletal deformities was observed in sea bass fed 5% EPA+DHA, almost 35% of the larvae exhibiting skeletal deformities and 10% other deformities (neurocranium, maxilla, and operculum). (51) concluded that unbalanced dietary fatty acid composition can affect fish development to a large extent.

(52) highlighted the important role of phospholipids (PL) in the structure and function of bio-membranes, in digestion and intestinal absorption of different components of the diet such as long chain fatty acids, proteins, vitamins and minerals. Also, PL contributes to optimize fish growth and survival, and decrease some deformities in different ages and types of fish. The optimization of the quantity of PL in a diet may enhance lipid deposition, increasing the energy available for growth and ovaries development (53, 54,55). Furthermore, PL may exert beneficial effects by providing essential nutrients, e.g. essential fatty acids, phosphorous, choline and inositol (56,52). (58) showed that phospholipids also have an antioxidant property, as well as feed-attractant properties (59). It has been suggested that fish at larval stages, are not capable of synthesizing PL at a sufficient rate to meet the requirements for cell formation and its components during the initial period of larval growth (60,61,62). Due to this suggestion, several fish larvae receive an abundance of phospholipids in their natural diets, whether from yolk sac lipids or from natural prey (52). Recommended requirements for PL ranged from 8% to 12% dry diet in larval fish (63). The PL requirement generally decreases with age or developmental stage, decreasing to around 2 to 4% for juvenile (52).

Requirement for dietary phospholipids has not been established for adult fish.

IV. NUTRITIONAL DISORDERS

Nutritional disorder is caused by vitamin deficiency and can impair the utilization of other nutrients, weaken the flesh of the fish and lead to disease, thus reducing the flesh quality. Pantothenic acid deficiency results in nutritional or clubbed gill disease. Inadequate nutrition can also have effect on the immune functions of fish (64). Adequate nutrition is essential for cells of the immune system to divide and synthesize effector molecules. The diet supplies the immune system with the amino acids, polyunsaturated fatty acid (PUFA), enzyme co-factors and energy necessary to support lymphocyte proliferation and the synthesis of effector (e.g immunoglobulins, lysozyme and complement) and communication molecules (e.g. cytokines, and eicosanoids). Fish nutrition research related to improving the status of fish health has become main priority in order to reduce the application of hazardous chemical substances. (65) claimed a new term for such field, which is "immunonutrition", defined as a study to improve immunological functions through specific nutrients and other feed compositions with higher level than those required for optimal growth. Nowadays, probiotic has become a part of aquaculture system functioning as production improved. However, the quantitative need for nutrients to maintain a normal immune function is relatively small compared to the requirements for growth and reproduction. It reduces fish morphological abnormalities affecting the image and profits of fish aquaculture. Nutritional deficiency signs usually develop gradually, and it is difficult to detect clear signs in the early stages. However, the culturist may obtain indirect clues of vitamin deficiency from such signs as poor appetite, reduced weight gain, and poor feed efficiency.

V. CONCLUSION

This study reviews the effect of nutrition on fish development, growth and health. Diet contributes toward increased growth and weight gain. Growth is due mainly to protein tissues and increase in body carcass. Lipids are important source of energy and fatty acids and are essential in the structure of biological membrane at both the cellular and sublevel. Fish could constitute an interesting model for studies on the impact of nutrition on higher vertebrate development, since very precocious stages are accessible for nutritional experiment.

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