Nutritional Programming in Fishes

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Abstract

The time has arrived to rethink and rewrite the inherent practices of feeding fishes. Since feed cost around 60-80% of the total expenses in aquaculture and that the feed ingredients are more fish meal based, it is quintessential to reform the practices more sustainably so as to reduce the cost and dependence over marine sources as well as to ease the fish in feeding its food. Moreover it is also important to understand the requirements rather than merely feeding the fish with our preferred choices and for this to happen, there is a need to understand the physiology and feed preferences of each species and also its habit and habitat where it perpetuates and resonates. Hence is the significance of nutritional programming which helps in promoting sustainable feeding strategies as it makes an association between early nutritional environment with growth, metabolism and development. Nutritional programming establishes conducive environment for the juveniles of fish to respond to exceptional nutrient rich feed like plant based feed fed to them so that they get easily acclimatized to such components in its later life without showcasing difficulty in intake and absorption, assimilating those better than the non-programmed fishes. Such better assimilation will improve feed utilization leading to less wastage and maximum feed conversion. The program intervenes the metabolic and immunological processes of fish so that it can respond better to similar diet later in its life. This will help in replacing the fish protein source by plant based protein with its proper utilization and with no compromise made over fish's meat quality. In addition, programmed nutrition also can evade the chances of health issues and can ensure good health to the new born as well, if the parent's feed is accurately programmed. Therefore the technique previously popular in mammals has to be employed in fishes too to suffice the aquaculture production and requirements of the world as this technique is capable of becoming a key tool in the industry's forward journey.

Keywords

Metabolism, Assimilation, Immunology, Nutrigenomics, Nutrigenetics, Precision Nutrition

Introduction

The possibility of metabolic programming emerged since the past 20 years (Lucas et al., 1998). Nutritional programming is an issue which has to be explored to understand the underlying mechanism as of how it modulated fish metabolism (Geurden et al., 2014). The environmental stimuli given at juvenile stage on a long term basis through this programming links with the epigenetics of the fish and gets transmitted from one generation to another generation (Gavery et al., 2017).Undoubtedly, to understand the vital communication of food components with the genes, there is a need to bring forth a substantial research into the "omics" of nutrition too (Trujillo et al., 2006).

Nutritional programming essentially aims at reframing the feeding strategies of fish to a more sustainable pattern for promoting plant based feed as the world is facing difficulty in obtaining animal based feed sources (Francis et al., 2001) without negatively influencing fish's growth, reproductive performance and its meat quality through evaluating its real metabolic phenomena and by regulating its nutrient intake and assimilation pattern (Panserat et al., 2019). The wild catch is depleting due to mismanaged fishing and therefore the stock is highly vulnerable. Hence it's advisable not to further utilize these for fish feed as this may pave way for ecosystem imbalance ultimately (Hua, K., & Bureau, D. P., 2012).

To shift to sustainable feed ingredients, plant based ingredients were incorporated previously itself into the fish feed but then the industry faced repercussions as the fishes didn't respond duly. The plant sources didn't have essential fatty acids for fishes and moreover the marine fishes could not synthesize these. Simultaneously, the plant ingredients were loaded with carbohydrates and the carnivorous fishes

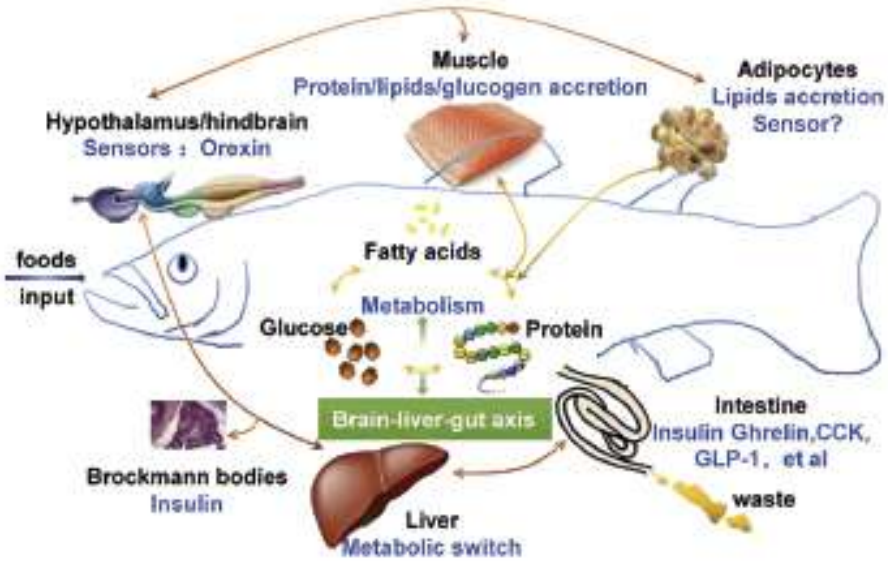

Figure 1: Intra-tissue communication of fish metabolism (Source: Zhang, Y., Lu, R., Qin, C., & Nie, G. (2020). Precision nutritional regulation and aquaculture. *Aquaculture reports*, *18*, 100496 [24].)

poorly metabolized carbohydrates (Conceicao et al., 2007), thus restricting all together the carbohydrates in fish feed (Hua, K., & Bureau, D. P., 2012). Hence is the importance of nutritional programming which turned out as a fruitful outcome out of the search for mechanisms to maximize the capacity of fish to utilize alternate energy sources (Conceicao et al., 2010).

The various positive outcomes of nutritional programming in fish has been reflected through its growth and sustenance pattern, body and brain development, and nutrient metabolism, mediated via reframed metabolic pathways and regulation of gene expression at its epigenetic level during a crucial phase of its life when they show high plasticity and flexibility in development (Hou, Z., & Fuiman, L.A., 2020). Best results came out from experiments with European sea bass, Long snout sea bream Atlantic salmon, Rainbow trout, Nile tilapia and many more.

Along with this boon has developed the concept of precision nutrition which aims to provide accurate nutrition to the fish, depending upon the species, developmental stage and breeding environment so as to decrease environmental perturbations and to enhance profits. Improvisation of feed-processing techniques and development of specific feed combination will serve the purpose of precision nutrition by acting as a key tool. This exemplifies that through successful nutritional programming, precision nutrition will itself get promoted and popularised (Zhang et al., 2020).

Methodology

The desired fish species is selected and the experimental plan is developed to expose it to programmed diet.

The initial phase in nutritional programming involves nutritional conditioning to larvae. The second phase is to repeat the same conditioning with the juveniles. The feed formulation and microinjection or dietary incorporation follows. Microinjection is essentially proved as an effective tool to alter nutritional composition of yolk (Rocha, F.S., 2015). Further as per each experimental design and its time frame, the fishes are randomly selected and analyzed- blood metabolite analysis, mRNA quantification, chemical composition analysis, gene expression assays or enzymatic assays are performed accordingly closely ensued by data analysis for final observations and results.

The Exemplary

The success stories of nutritional programming of few among the various fishes tested with, are as given below. Metabolic programming by dietary carbohydrate in European sea bass larvae with 34% of starch in feed as a stimulus brought positive results. The outcome of the experiment howsoever also suggested that the larval conditioning may fade over time and hence it is appropriate to give nutritional stress pulses regularly during the first months of life to fish for consistent results (Zambonino-Infante et al., 2019).

Studies in *Hippocampus reidi* (long snout sea bream) revealed that nutritionally programmed parents produce better offspring (Otero-Ferrer et al., 2016).

Atlantic salmon responded positively to programmed diet when fed 3 months prior with plant based feed. Later the fish exhibited great assimilability with the feed reflecting in its growth, feed retention and feeding efficiency. A study revealed 24% higher growth rate with vegetable based feed in its early development phase as against marine based diet. Nutritional intervention improved carbohydrate, protein and lipid metabolism by 28%, signaling by 15% and immune, endocrine and translation by 7% (Vera et al., 2017). Further it induced an up-regulation in genes involved in phosphorylation, pyruvate metabolism, TCA cycle, glycolysis and fatty acid metabolism in liver (Vera et al., 2017).

In rainbow trout, nutritional programming with sustainable feed affected the routes of sense recognition, synaptic communication, cognitive activities of the body and the activities neuroendocrine peptides in the brain. As of liver, the pathways associated with xenobiotic metabolism, proteolysis and cytoskeletal cell cycle control are affected (Balasubramanian et al., 2016).

For Nile tilapia, 2M microinjection of glucose into its yolk reserve during its juvenile stage had several positive effects on its adult like, efficient use of glucose with protein-sparing effects, inducting lipogenesis and decreasing amino acid catabolism, leading to its improved growth performance (Kumkhong S., 2020).

The scientists at University of Texas through their study revealed that the fish red drum gets its DHA which

properly programmed nutrition is provided, the benefits are innumerable, ranging from cost effectiveness to high survival rate and best growth and reproductive performances (Fuiman, L. A, & Perez, K.O., 2015).

As of zebra fish adult programmed with carbohydrates, it says that the time slot from culture to weaning is an important period for potential modification of its long-term physiological functions and that it is possible to permanently alter its carbohydrate digestion, transport and metabolism through early nutritional programming in this time frame (Fang et al., 2014).

While, the zebra fish when fed with plant protein, the programmed fish group expressed improved middle intestinal lining area with highest villus length to width ratio pointing towards the mechanism behind improved feed

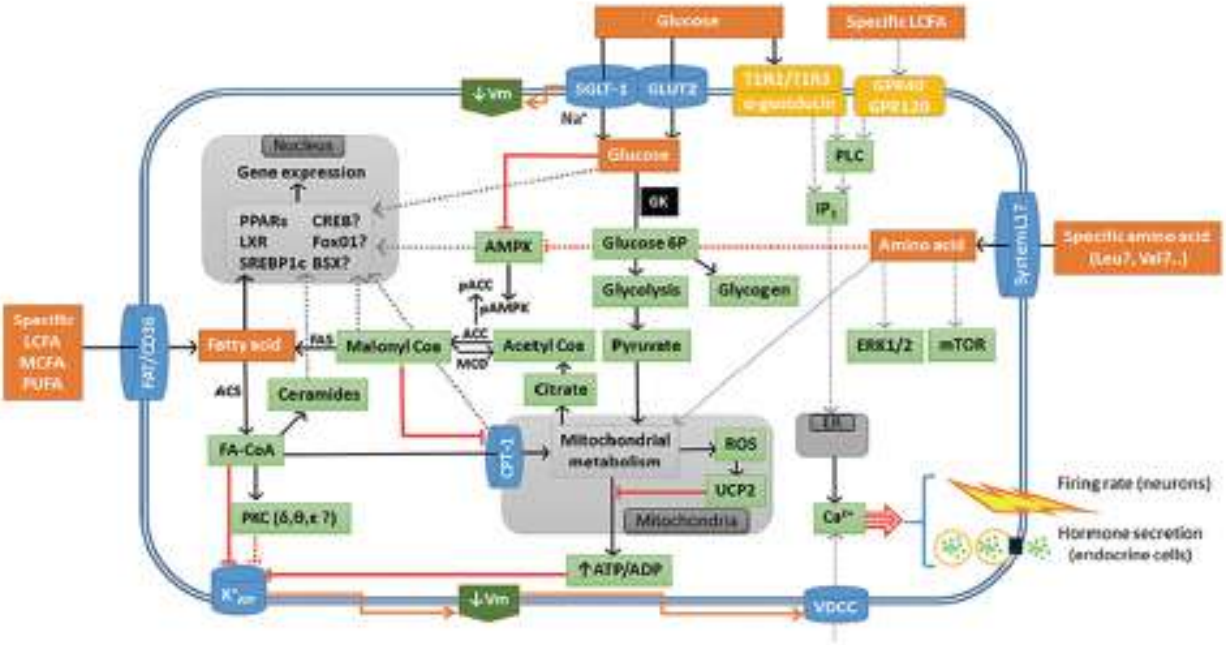

Figure 2 : Schematic drawing with a model of different sensing systems for glucose, fatty acid, and amino acid in sensor cells in fish (Source: Conde-Sieira, M., & Soengas, J. L. (2017). Nutrient sensing systems in fish: impact on food intake regulation and energy homeostasis. *Frontiers in neuroscience*, *10*, 603 [4].)

is contained in its yolk for its offspring's proper development comes from the its food source- shrimp and crab. Decline in these food resources due to damaged ecosystem is therefore likely to impact the young one's survival. Hence they reported the significance of metabolic programming here for the declining fish populations to recover as one of the important conservation strategies amongst the other strategies. Several countries release millions of young ones into the natural water bodies to replenish the natural fish stock by hatchery production and rearing. In this step if

assimilation as endocrine and morphological adaptation of the digestive system culminating in improved growth performance (Kwasek et al.,2020).

Another case is with the same zebra fish as a model organism instead. It is fed nutritionally programmed feed to increase its experimental vigor and vitality for its nutrigenomics and nutrigenetics study and also for analyzing the effect of variation at genetic level on dietary response and the role of nutrients and bioactive food

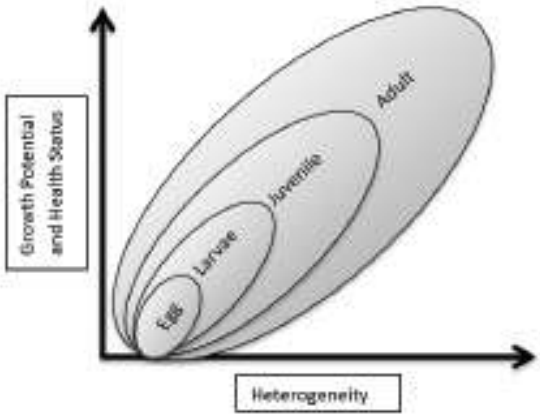

Figure 3 : Graph expressing the relationship of fish's growth potential and health status with heterogeneity through its various life stages

components in gene expression respectively (Fenech et al.,2011), ultimately enhancing its value and efficacy as a model organism. The zebra fish community will benefit from an increased understanding of the nutritional needs of zebra fish (Williams, M.B. & Watts, S.A., 2019). Hence similar studies are the need of the hour and especially concerning such models.

Prospects of Nutritional programming

The environmental factors confronted during early developmental stages, the differences in each fish's physiology and survival strategies, nutritional intervention type and time of developmental windows affects the process of nutritional or metabolic programming.

Nutritional programming in fact invokes a permanent functional change in the fish's physiology by affecting its crucial organs development accordingly and adaptively tunes its body to the changed trophic condition and environment which it may likely encounter in its future too.

Several studies are happening across the globe in testing the sustainable feed (plant-based) served to fish with minor inclusion of animal based components. Successful results have come up while testing with different species under different conditions and that an universal strategy is yet to come out.

In fact the outcome of this research will influence and impact academia, feed industry and the consumers. New feed formulation will pop-up to feed the programmed fish to better utilize its food thereby cutting feed cost as the sustainable feed has replaced the costly marine ingredients, with best flesh quality ensured anyhow. Further with programmed fish, its health and well-being is guaranteed on a better scale benefitting the industry as a whole from losses. Nutritional programming which incorporated plant protein is also said to alter the gut epithelial lining, subsequently increasing fish's resistivity to negative side effects of plant protein, improving its ability to cope with these alternative raw materials and better assimilate them in later life. With the processing sector, the improved meat quality is a boon.

Epigenetic mechanisms such as genomic imprinting may affect programming. These epigenetic modification is stimulated by environmental changes occurring in both somatic and germ cell lineage during development. Nutritional changes made at earlier stage in fact modify cell-specific DNA methylation patterns and these altered DNA methylation patterns in specific cells are transmitted to the daughter cells by replication too, whereby the initial modifications are immortalized (Patel, M.S., & Srinivasan, M, 2002).

But however certain research like with respect to the case of European sea bass, still there is a need to instill the programming effects in the fish till its adulthood and for this the possible biological mechanisms to imprint the stimulus includes: adaptive gene expression changes, preferential clonal selection of adapted cells in programmed tissues and programmed differential proliferation of tissue cell types.

Way Forward

With all these benefits, it is understood that nutritional programming has a huge future ahead in the aquaculture sector. Necessary scientific and technical intervention will lead forward. Understanding fish nutritional requirements and those factors influencing these with appropriate management strategies will help in building a robust and sustainable fisheries sector. However, practical implication with due awareness creation among farmers and other stakeholders is essential to succeed ultimately.

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