Better Defining Nutritional Requirements of Fish and the Nutritive Value of Feed Ingredients: Lessons from Integration of Experimental Data from a Wide Variety of Sources

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Abstract

Each and every year hundreds of studies are published on the nutritional requirements of aquatic animals and the composition and nutritive value of different feed ingredients. However, knowledge integration efforts carried out in recent years at the UG/OMNR Fish Nutrition Research Laboratory have indicated that, in general, less than 50% of the published studies have appropriate experimental design, contain sufficient information or have results deemed sufficiently meaningful and credible results to be used in statistical meta-analyses. Small but meaningful improvements in the objectives, scope, and experimental design of research trials, as well as, in the quality and completeness of information reported in scientific papers could greatly improve the quality and relevance of research efforts in aquaculture nutrition.

Research trials should be designed with the perspective of potential end users (e.g. feed manufacturers) in mind. Nutrient requirements trials should not ideally have fewer than six (6) graded levels of the nutrient studied and report sufficient information on the composition and digestibility of the experimental diets, and growth performance and body composition of the experimental animals. In the case of research on the nutritive value of feed ingredients, more emphasis should be on assessment of available nutrient "contributions" of ingredients to the diet (i.e. the bioavailability of nutrients in ingredients) rather than "absence of effect" of test ingredients when included in luxurious (e.g. high fish meal) diets. Finally, nutritional models and data integration and analysis systems should be developed and widely used to more effectively compile, analyze, interpret and valorize information generated by aquaculture nutrition research efforts carried out around the world.

Keywords: nutrient requirements feed formulation, feed ingredients

Introduction

Aquaculture feed manufacturers around the world are facing significant challenges: High cost and variability in the availability and quality of feed ingredients, increasing competition, small profit margins and rapidly evolving market requirements are factors that are creating a strong incentive for feed manufacturers to pay very close attention to the composition and cost-effectiveness of their feeds. Over the years, aquaculture feed manufacturers have had to progressively decrease fish meal and fish oil levels in their feeds, and increasingly rely on the use of an increasingly diverse array of feedstuffs of plant, animal and microbial origins. They also have sought to optimize the composition of their feed to further reduce cost, improve productivity and efficiency, or better fit market requirements and consumer demands and concerns.

In this context, feed formulators require increasingly accurate information on the nutrient requirements of the animal cultivated and on the nutritive value of economical feed ingredients. It is very fortunate that aquaculture nutrition is a very dynamic field of research and that a very large number of studies are carried out each year on the nutritional requirements of aquaculture species and on the nutritive value of a wide variety of feed ingredients. However, making sense of published information and developing a wholesome understanding of "state-of-the-art" in aquaculture nutrition is not simple, especially given the great diversity of animal species and ingredients studied and methodological approach used and the complex interactions between nutritional, endogenous and environmental factors.

Efforts undertaken to systematically compile, standardize and analyze data from published studies indicate that the overall quality of the research efforts in aquaculture nutrition is highly variable and could be greatly improved by simple improvements in the objectives, scope, and experimental design of research studies, as well as, in the quality and completeness of information reported in scientific papers. Some lessons and observations derived from knowledge integration efforts carried out at the UG/OMNR Fish Nutrition Research Laboratory are presented in this short paper.

A Dynamic Field of Research but Fragmented State-of-the-Art

Aquaculture nutrition is a very dynamic field of research that is generously supported by numerous granting agencies and industry stakeholders worldwide. Hundreds of scientific papers, technical documents, and scientific communications (abstracts) are published each year on the nutritional requirements of a large number of aquaculture species and on the chemical composition and nutritive value of an increasingly wide variety of feed ingredients. For example, a recent review of the literature yielded about 300 scientific and technical papers on essential amino acid requirements of fish and crustacean over the past five decades (1). In parallel, more than 1000 scientific documents on the nutritive value of soy products and rendered animal proteins and fats for aquaculture species have been published in the scientific and grey literature (2).

Systematic efforts undertaken at the University of Guelph Fish Nutrition Research Laboratory and elsewhere to compile and analyze data from hundreds of published studies using mathematical models, statistical meta-analysis approaches and advanced nutritional models (1, 2, 3, 4, 5, 6, 7, 8) have indicated that, taken globally, the research effort in aquaculture nutrition has been of highly unequal quality.

In general, less than 50% of the published studies surveyed had appropriate experimental design, contained sufficient information or had results deemed sufficiently meaningful and credible results to be used in statistical meta-analyses (1, 2, 3, 5, 6, 7).

The large number of animal species cultivated (> 200 species), the great range in the body weights of experimental animals (from a few mg to more than 5 kg), the large number of essential or conditionally-essential nutrients (about 50 nutrients) and feed ingredients studied also results in great dilution of the research efforts and further fragmentation of the body of knowledge (9).

Globally, there is a need for small but significant improvements in the focus of studies, the scope and quality of the experimental design and methodological approaches used, the characterization of the diets and ingredients used, and in the provision of more information in published scientific papers.

Characterization of Nutrient Requirements

Requirements of different fish and crustacean species at different life stages and reared in different production systems (9).

Salze *et al*. (1) in an effort to systematically compile, standardize and analyze published data from 249 published studies on essential amino acids (EAA) concluded that less than half of the original studies surveyed could be considered for meta-analysis. Screening of the studies with a series of selection criteria yielded a final dataset comprised 109 studies, which is a very small number of studies considering that there are 10 EAA and that 28 teleost species were represented in this dataset.

An important cause of rejection for studies in meta-analysis is often due to the lack of reported information which precluded the calculation of the various variables and parameters (1, 2, 3, 4). Simple parameters, such as feed intake (feed served) and the dry matter content of the diets, are frequently not reported in published papers. On many occasion, the chemical composition of the experimental diets does not fully compute with the composition of the ingredients used in the formulation of these feeds. The information reported on the source, characteristics and composition of ingredient tested in many studies is often very shallow. Useful parameters, such as digestibility of nutrients of the experimental diets and the body composition of the animals, are reported in less than 50% of published studies. The poor growth performance or feed efficiency achieved in growth trials negatively affects credibility of many studies. Finally, many studies include too few graded levels of nutrient or ingredient studied and this limits the ability to meaningfully analyze the results using different response-fitting models (1).

Salze *et al*. (1) concluded that simple steps can be taken to improve the quality and relevance of future nutrient requirements studies and allow the development of more precise estimates of essential nutrient requirements. Experiments should not ideally use fewer than six (6) experimental diets, and report sufficient information on diet composition, growth performances and husbandry information. The graded dietary levels of the test essential nutrients should include clearly adequate levels so an obvious plateau can be observed. Concomitantly, equally clearly deficient levels should also be included to ensure sufficient differences between treatments receiving suboptimal levels.

While improving the accuracy of estimate of essential nutrient requirements is critical, determining how the findings of nutrient requirement studies can be translated into meaningful and robust nutritional and feed formulation guidelines is equally important. It is a complicated issue that is too often overlooked by aquaculture nutrition researchers (9, 10,11).

Aquaculture feeds are characterized by the wide nutritional specification to which they are formulated to. This is expected given the very large number of fish and crustacean species produced around the world using feed-based production systems. However, the protein, lipid, starch and digestible energy contents of feeds can significantly vary not only as a function of species and life stages for which they are formulated (trout vs. tilapia feed, starter vs. grower vs. finisher feed), but also as a function of a myriad of other factors, such as production systems, farmers' or feed manufacturers' preferences, environmental constraints, and socio-economical conditions (e.g., fish price, access to credit, degree of risk). Most fish feed manufacturers have to serve a large client base cultivating numerous fish and invertebrate species in very different production systems (ponds vs. cages, marine vs. freshwater environment, etc.) and socio-economical contexts (small farmers vs. large vertically integrated corporations) (12).

These factors, as well as, the multitude of opinions with regards to optimal levels and modes of expression of essential nutrient requirements limits the ability of manufacturers to meaningfully translate scientific advances into practical and cost-effective feed formulation guidelines (9, 10, 11). There is clearly a need for more consideration of how the information may be potentially used when designing research trials (9).

Contrasting the response of animal to increasing essential nutrient levels in different dietary matrices (e.g. diets with different digestible energy levels), and different species and life stages may allow to gain knowledge on the impacts of these different factors on essential nutrient utilization and requirements and enable the development of more robust feed formulation guidelines and models (10, 11).

Evaluating the Nutritive Value of Feed Ingredients

Over the past five decades, dozens of different protein and lipid sources have been evaluated in hundreds of "practical" feeding trials. Many of these trials focused on replacing fish meal, fish oil or other high quality protein and lipid sources by putatively more cost-effective protein and lipid sources.

In many feeding trials, the control diet is formulated with high fish meal levels and/or all essential nutrients are supplied greatly in excess of requirements. The test ingredient is included at graded levels and effect on growth performance is monitored. Under these conditions, the evaluation of the nutritive value of the "test" ingredients is not very robust nor is it specific enough. For example, a certain level (e.g. 20%) of the test ingredient may be observed to support optimal growth performance in feeds formulated to very high essential amino acid levels (e.g. high fish meal feeds). However, the same level of test

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ingredient may not be suitable for feeds formulated with low fish meal level and/or lower essential nutrient levels (13, 14).

There is a need to refine methodological approaches so that the focus is on assessment of available nutrient “contribution” of ingredients to the diet (i.e. the bioavailability of nutrients in ingredients) rather than “absence of effect” of test ingredients (13).

Most studies focusing on digestibility of nutrients carried out so far have focused apparent digestibility of proximate components (dry matter, crude protein, crude fat, gross energy). (15) More efforts need to be invested in systematically investigating the effects of numerous factors that can affect the individual nutrient levels and bio-availability in feed ingredients. More emphasis should be placed on characterizing of the nutritive value of the different batches of the same type of ingredient with increasing emphasis on individual nutrients or components that are rarely analyzed for standard analysis scheme (e.g. proximate analysis) (13, 15).

Keeping an Eye on the Prize

In defining the focus and objectives of research projects, aquaculture nutrition scientists should keep the perspectives of feed manufacturers and aquaculture producers in mind. They ideally should first focus on generating information needed to meaningfully address key economical and production issues (growth, feed efficiency, disease resistance, product quality, etc.). The focus also should be on generating information needed to be able to adapt feed formulations to an ever more competitive and demanding market and to stricter environmental constraints and consumer demands.

Increasing collaboration between feed manufacturers, ingredient suppliers, fish producers, and research organizations has been instrumental in improving the quality and relevance of fish nutrition research in recent years. Many aquaculture feed manufacturers are investing heavily in research and development activities and have established own research facilities to test their commercial feed formulations, determine the effect of feed composition/nutritional specifications and feed ingredients on growth and feed efficiency of animals grown under commercial-like conditions. This has probably resulted in improvement of the quality of feed available to aquaculture producers (12). However, limited amount of information from these efforts trickles down to the global aquaculture nutrition community since the information generated is generally proprietary and is closely guarded from public disclosure for competitive advantage. Nonetheless, a healthy, arm-length, relationship with different industry stakeholders can truly help commercial relevance of academic research efforts in aquaculture nutrition.

Despite very intensive research efforts, there is a dearth of information on the nutrient requirements of some of the most commercial important species. It would be recommendable to increasingly focus research efforts on the 12 to 15 fish and crustacean species (e.g., cyprinid specie, tilapias, Pangasid catfish, Atlantic salmon, Penaeid shrimp, etc.) that represent more 80% of the global farmed fish and crustacean production.

The focus of research efforts in aquaculture nutrition in recent years has increasingly been on more fundamental or mechanistic studies based on the use of sophisticated and cutting-edge techniques and approaches (enzyme activity, gene expression, genomics, proteomics, etc.). This shift has occasionally been at the expenses of more practical (basic) studies. Ideally, mechanistic studies should be to determine or understand the "root causes" of meaningful differences between different phenotypes rather than as a tool to find small, potentially inconsequential, differences between different treatments, diets, ingredients, etc.

Potential Value of Nutritional Models for the Integration and Interpretation of Information

Keeping up with progress and developing a wholesome understanding of “state-of-the-art” in aquaculture nutrition is often difficult. It is often very difficult to interpret data from different studies since these are derived from studies using dramatically different types of experimental protocols, feeds, analytical methods, and data analysis strategies/models. The great plasticity of growth and other performance criteria in fish and crustaceans reared under different environmental conditions complicates interpretation of dietary effects. Meaningful integration of current knowledge into comprehensive, yet straightforward and adaptable frameworks represents one of the great challenges in aquaculture nutrition (2, 8, 16, 17).

Decades of use in different animal production (dairy, beef, swine, poultry) sectors have demonstrated the value of nutritional modeling as an effective way of compiling, integrating, and interpreting available information (research-based or farm-specific information) and enabling the development of practical and reliable tools for feed formulation and/or production, feeding, and waste outputs management.

A relatively large number of nutritional models have been developed for fish and crustaceans over the past four decades (8, 16, 17). However, the nutritional models developed so far for fish all present important limitation and are not sufficiently flexible and reliable to be applied to a wide range of conditions (8). Recent attempts to adapt advanced nutritional models that have been successfully used in other livestock production have not been highly successful (8). It is becoming evident that it is not always possible to simply transpose ready-made concepts and models from mammals and birds to aquaculture species (8). More comprehensive and pragmatic frameworks that incorporate the latest information in terms of nutrient requirements and utilization by fish and crustaceans need to be developed. Future nutritional models need to be robust and increasingly mechanistic and rational. They should be applicable to a broad number of species cultivated commercially, and also need to be continuously evolving and improving as new information becomes available (16, 17).

In recent years, significant efforts were invested by a limited number of research groups to develop mathematical nutritional models that are more advanced than the current least-cost feed formulation programs based on linear programming with the objective of helping fish

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feed manufacturers optimize feed composition to meet nutritional requirements of fish and specific production objectives in a cost-effective fashion, while dealing with increasingly complex array of feed ingredients (2, 3, 4, 5, 6, 7, 8, 16, 17). More efforts now need to be invested in developing accessible and user-friendly interfaces for nutritional models so that researchers, feed manufacturers, and aquaculture producers can more easily use these tools and work cooperatively to meet current and future challenges (16,17).

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