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# Optimization of the Formulation of Aquaculture Feeds as Important Factor in the Sustainability of the Aquaculture Sector


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**Introduction**

The development of cost-effective aquaculture feeds has been a key factor in the sustained and rapid development of the aquaculture industry around the World (Tacon, 2004). The availability of highly nutritious and relatively economical feeds has enabled the intensification of aquaculture production in many parts of the world. Efforts have been invested to improve the cost-effectiveness of aquaculture feeds through modification of their ingredient composition, nutritional profiles and correspondence with market expectations. Today, aquaculture feeds are formulated with complex mixtures of a variety of ingredients to very specific nutrient specifications using sophisticated feed manufacturing processes. Aquaculture feed production currently stands at about 35 to 40 million tonnes. It is reasonable to expect that this industry will continue to expand. Many experts are predicting that the production volume of aquaculture feeds may more than double over the next two or three decades as aquaculture production increases. This success and the sustained expansion of the industry have brought (and will continue to bring) numerous challenges. The competition amongst the feed manufacturers is also increasing fierce, profit margins are generally small and shrinking and the clients (aquaculture producers) more demanding. Increasing scrutiny by certification bodies, distributors and consumers is also bringing new challenges.

In a context of significant competition, manufacturers are required to formulate to increasing lower nutritional specifications and narrower variability in order to minimize feed cost and yet meet client expectations. This can be very complicated since many feed manufacturers have to formulate feeds for very large number of fish and crustacean species at different life stages and reared using different types of production systems. The high demand has driven up prices and creates volatility in the supply of some ingredients which, in turn, has forced feed manufacturers to play with an increasingly diverse portfolio of more economical raw materials, each of which having their own characteristics and limitations. At the same time, the manufacturers have to constantly ensure that their feeds are able to sustain high growth rates, feed efficiency, disease and stress resistance in the animals fed these feeds, as well as, ensure a final product of high quality that meet market’s expectations.

Aquaculture nutrition community can, in part, work on addressing some of these major issues through an improved and more balanced understanding of the requirements of the animals and of the quality of feed ingredients. Efforts should be invested by the sector in better determining and predicting the nutritional requirement of the animals, in the broader and more detailed characterization of the nutritive value of feed ingredients, in the development of additives that can help address some issues, and in the implementation of effective feed formulation and quality assurance tools and processes. This short paper briefly discusses some of these issues related to characterization of nutrient requirements and nutritive value of feed ingredients. It highlights some of the current limitations or shortcoming in the current approaches and attempts to propose some directions for future research and development efforts.

## 1) Effectively Determining and Meeting Nutritional Requirements

In a context of significant competition and low profit margins, aquaculture feed manufacturers are required to formulate to increasing lower or narrower nutritional specifications (‘specs’) in order to minimize feed cost. Decreasing specs for certain nutrients (e.g. lysine, methionine, DHA, available phosphorus) can significantly reduce the cost of feeds. The formulation of cost-effective aquaculture feeds adequately meeting the nutrient requirements of animals, while not being too wasteful, can be a very delicate balancing act.

Perhaps a relatively unique feature of aquaculture feeds is that they are characterized by a wide range of nutritional specifications. 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). Formulating “on the edge” is very complicated in this complex sector.

### Good Level of Efforts but Too Many Species!

Significant efforts have been invested over the past six decades on the definition of the nutrient requirements of numerous fish and crustacean species and the body of knowledge is growing significantly every year. Reviews of the literature and nutritional recommendations are provided on a relatively regular basis by different groups of researchers or committee of experts. The relatively new NRC (2011) 'Nutrient' Requirements of Fish and Shrimp and other reference documents are providing feed manufacturers with a reasonably good basis for the formulation of feeds meeting of requirements of many of the commercially important aquaculture species.

However, the number of fish and crustacean species studied by different investigators is staggering and this leads to dilution of research efforts. Globally, there is need for significant improvements in the focus of nutritional studies, and the scope and quality of the experimental efforts invested in the definition of essential nutrient requirements of commercially important species. It would be recommendable to increasingly focus the research efforts on the 15 or so fish and crustacean species (e.g., Chinese carps, Indian major carps, Nile tilapia, Pangasid catfish, Atlantic salmon, Pacific white leg shrimp, etc.) that represent the bulk of the global farmed fish and crustacean production.

Studies have suggested that some of these nutrients, such as phospholipids, cholesterol, nucleotides and arachidonic acid (ARA, 20:4 n-6), abundant in fish meal and other animal feedstuffs, are essential to some species and/or for the larval stage of certain species.

Nonetheless, there is mounting evidence that most fish and crustacean species can be considered "obligate carnivores" (of sort) and that some nutrients rich in animal products may often be overlooked in formulation and nutritional requirement studies. More research needs to be carried out to determine if these nutrients are truly essential or under what circumstances they are required or beneficial.

**Estimates of Nutritional Requirements Affected by Many Factors**

Estimates of requirements are generally derived from studies with young fish fed diets containing purified and chemically defined ingredients that are highly digestible and, generally, represent minimum nutrient concentrations required for maximizing performance of these young animals under laboratory conditions. While this type of approach and definition of 'requirement' may sound relatively simple and straightforward, reality is a lot more complicated. Significant differences may exist in the experimental conditions (diet composition, experimental design, duration of study, fish trains, life stages), measured parameters (live weight gain, protein gain, enzyme activity, body stores, histological changes), performance achieved (growth rate, feed efficiency), and methods of analysis of the results for 'similar' studies. Consequently, very different 'estimates' of requirement can be derived from similar studies. Moreover, the same dataset (e.g. data from one single study) can also be interpreted in very different ways through the use of different mathematical models to analyse data or by simply putting more emphasis on different parameters (body stores vs live weigh gain vs enzyme activity). Moreover, how requirements evolve with changes in the genetic, weight, growth rate or feed conversion achieved, or health status of the animal is something that, in my humble opinion, has not been adequately studied for aquaculture species.

Defining a nutrient requirement value is clearly not a straightforward thing and yet published estimates of requirements are too often taken at face value and/or misunderstood. It must be recognised that published estimates of nutrient requirement are derived from consensus among 'experts' and are thus very much products of opinion and not some sort of unchallengeable truth. Feed formulators should ideally dig in the primary research literature for the real data and develop their own opinion. Feed manufacturers should also focus a significant part of their R&D efforts toward verifying the adequacy and suitability of their nutritional specifications.

**Information Available or How is it Used?**

The mode of expression of requirement is an issue that has not received sufficient attention. There are numerous diverging opinions with regards to appropriate modes of expression of essential nutrient requirements. It is especially the case for essential amino acid (EAA) for which very different modes of expression of requirement are used, often interchangeably, in the literature. These different modes of expression are based on different, often diametrically opposed, assumptions. In practice, the use of different modes of expression of EAA requirement can often result in dramatically different nutritional recommendations. Individual EAA levels deemed adequate may be very different depending on the mode of expression adopted and the composition of the diet formulated. This is a significant issue since feeds for a given species are formulated to widely different protein, lipid, starch, and digestible energy levels. The root cause of these conflicting views is our limited understanding of how endogenous and dietary factors affect EAA utilization and requirements of fish.

Finally, requirements are generally amount of nutrient in a biologically available form that needs to be delivered to the animal. It is important in this context to consider a reasonable safety margin to account for potentially lower digestibility or bioavailability of nutrients in practical ingredients, for losses of nutrients during manufacturing and storage of the feed, and for potential 'changes' in nutrient requirements imposed by various environmental or endogenous factors. What represents a reasonable safety margin is again something up for discussion.

**The Potential Value of Nutritional Modelling**

Keeping up with progress and developing a wholesome understanding of “state-of-the-art” in aquaculture nutrition is often difficult, especially given the great diversity of animal species and ingredients studied, the methodological approach used, the socio-economical contexts in which the research was carried out, and the complex interactions between nutritional, endogenous and environmental factors.  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 (Bureau et al., 2002; Dumas et al., 2010). 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 (Bureau et al., 2002; Dumas et al., 2010). 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 (Hua et al., 2010; 2012). 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.

There is also a need to improve the current least-cost feed formulation programs that are simply based on linear programming to include non-additive interactions the chemical form under which nutrient are provided and the effects of various exogenous factors (Hua and Bureau, 2009a&b, 2010). More efforts also need to be invested in developing accessible and user-friendly interfaces for models so that researchers, feed manufacturers, and aquaculture producers can more easily use these tools and start to work more cooperatively to meet current and future challenges.

**2) Characterization of the Nutritive Value of Feed Ingredients**

Most aquaculture feeds are generally formulated to high protein (> 25%) and lipid (> 6%), levels and may contain significant levels (>10%) of expensive marine fisheries ingredients (fish meal, fish oil, squid liver, shrimp head meal, etc.) to ensure good feed intake and growth performance of the animals. Up to about 10 years ago, fish meal and fish oil represented about 70% of the weight of most commercial salmon and marine fish and crustacean species feeds sold worldwide. The price of fish meal (Fair Average Quality (FAQ) basis 65 percent protein, FOB Peru) has surged from about $500 to more than $1,600/MT over the past decade. The price of fish oil is also roughly 4-fold higher than it was 25 years ago.

The FAO concluded that the availability of fish meal and fish oil was one of the main constraints limiting the growth of aquaculture (FAO 2009). However, with an annual aquaculture feed production of about 40 million metric tonnes (MMT) and an annual fish meal production of about 5 MMT, fish meal now can only represent globally 12% of the weight of aquaculture feeds. Consequently, the story is not really about "fish meal replacement" anymore. Fish meal plays a critical role as a supplier of specific nutrients ((and often poorly characterized one) and not as a "major" ingredient.

Feed manufacturers have been increasingly relying on the use of an increasingly diverse array of alternative feedstuffs of plant, terrestrial animal or microbial origins, each of which having their own characteristics and limitations. While a number of research trials have shown that feeds can be formulated without fish meal provided the feed is formulated with high quality ingredients (including ingredients of animal origin and various nutritional supplements). However, several studies have shown that formulating fish feeds without fish meal is not always an easy feat.

Accurate assessment of nutritive value of feed ingredients is extremely important for the formulation of cost-effective feeds with lower levels of high quality fish meal. Better characterization of the nutrient composition of feedstuffs is essential to improve their "valorization" by least-cost feed formulation programs. More efforts need to be invested in systematically investigating the effects of numerous factors that can affect the nutritive value of feed ingredients.

Studies have suggested that some of these nutrients provided by fish meal and other feedstuffs of animal origins (eg. phospholipids, cholesterol, and arachidonic acid) may be essential or conditionally essential for some species or at specific life stages of some species. Recent studies have shown significant benefits from supplementing plant-based "grower" fish feeds with cholesterol, taurine, and hydroxyproline, three nutrients also abundant in fish meal and other animal products. More research needs to be carried out to determine if these nutrients are truly essential or under what circumstances they are required or beneficial. Nonetheless, replacing fish meal may also means paying attention to once overlooked nutrients present in animal products.

**Dealing with Variability in Quality of Ingredients**

Sourcing an increasing diverse array of raw materials from different suppliers can also results in greater probability for significant variations in the quality of the raw materials purchased. The high price of certain feedstuffs may also incite unscrupulous suppliers to adopt deceptive practices, such as product adulteration. In this context, the sector needs to have to invest significant resources in the characterization of the nutritive value of different feedstuffs (and batches thereof) and in quality assurance. Larger manufacturers often need to source the required high volumes of certain raw materials from multiple suppliers. Small manufacturers due to their lesser needs may be able to source from single suppliers but, at the same time, may be even more at the mercy of capriciousness of the markets. The production of highly nutritious and cost effective feeds with an increasingly wide array of feed ingredients obtained from different suppliers is clearly not an easy task. This is certainly keeping some feed formulators awake at night.

Sourcing of raw materials from different countries, manufacturers or brokers arguably results in greater probability for significant variations in the quality of the raw materials purchased. The high price of certain feedstuffs (for example fish meal) may also incite (unscrupulous) suppliers to adopt deceptive practices, such as product adulteration (for example blending less expensive raw materials with more expensive raw materials). Feedback from the field indicates that variability in the nutritive quality and adulteration of feedstuffs are not a thing of the past. In this very complex context, quality assurance (QA) plays an extremely important role.

QA usually involves the definitions of specifications for the purchasing of the raw materials and for the inspection and analysis of these raw materials as they are received at the feed mill. Most, if not all, aquaculture feed manufacturers have adopted some sort of QA process and invest very significant financial and staff resources in this. The main emphasis of QA systems in place is on chemical composition, mainly on proximate analysis (crude protein, crude lipids, crude fibre, etc.), of the raw materials. Relatively little emphasis is placed on direct measurements of individual nutrient or contaminant levels due to the often prohibitive cost of this type of analysis. Near Infrared Reflectance Spectroscopy (NIRS) is widely used by most aquaculture feed manufacturers around the World to obtain rapid and generally accurate estimation of the proximate and individual nutrient levels of batches of raw materials. However, measurements obtained with these technologies must be calibrated carefully against diet characteristics that are biologically meaningful, such as content and bioavailability of nutrients, bio-actives and contaminants.

More attention also needs to be paid to accurately characterizing of the nutritive value of the different types of ingredients (and batches thereof) available on the market, with increasing emphasis on minor nutrients and chemical components.  Relatively little emphasis has been placed on assessment of the nutritive value of different batches of raw materials by academic research groups. There is some experimental evidence that significant variability exists in the digestibility and bio-availability of the individual nutrients of different batches common aquaculture feed ingredients. Fish meals, feather meals, meat and bone meals and DDGS often come to mind as ingredients that can vary quite significantly in terms of digestibility and nutritional quality. However, variability in digestibility and nutritive value is not only limited to these ingredients.

It is unfortunate that so few research efforts are invested by aquaculture nutrition researchers on these issues that are so important to the aquaculture feed industry. Better research and more data would really help guide QA efforts of aquaculture feed manufacturers. For example, NIRS is highly dependent on the availability of high quality raw data on the composition and nutritive value (for example amino acid digestibility) of different raw materials so that reliable calibration of the instruments can be done. This is one area where academic research groups could play a very important role and yet are virtually absent.

Other rapid but more direct ways of assessing the nutritive value of different batches of raw materials are also required. Pepsin digestibility is probably one of the most widely used tests to estimate digestibility of protein. However, there is some controversy as to the proper concentration of pepsin to be used and the applicability of this type of tests to different aquatic animal species and different raw materials. There is very limited published experimental (animal) studies examining the reliability of pepsin digestibility assays and defining their limitations. Other in vitro tests, such as pH-stat protein digestion assays have been developed but they also suffer from a lack of standardisation and lack of validation. Right now, efforts are really disparate and different groups are proposing very different approaches. There should be systematic and concerted efforts on this topic.

Turning away raw material shipments is not always feasible in the current climate. It is perhaps more important for feed manufacturers to learn how to better identify and determine the consequence of variability in composition and learn how to safely and appropriately use raw materials that differ from the established specifications. This is another important role in which academic research laboratories could play a role.

Too much reliance on ‘laboratory tests’ to assess quality of raw materials may also result in a certain lost of touch with reality. It is my experience that frontline QA personnel and general feed production staffs are not always highly aware of how different raw materials should look, smell and feel like. These are primary indicators that something may not be ‘right’ with the quality of raw material received. Clearly, more training of front line staff is needed.

## References


Bureau, D.P., Kaushik S.J., and Cho C.Y. 2002. Bioenergetics. pp. 1-53. In : Halver, J.E. and R.W. Hardy (Eds.) ***Fish Nutrition***, III Edition, Academic Press, San Diego, California, USA.

Bureau, D.P. and Hua, K.. 2010. Towards effective nutritional management of waste outputs in aquaculture, with particular reference to salmonid aquaculture operations. *Aquaculture Research* 41 777-792.

Dumas, A., J. France and D.P. Bureau. 2010. Modelling growth and body composition in fish nutrition: Where have we been and where are we going? Aquaculture Research, 41: 161-181.

FAO, 2009. The State of World Fisheries and Aquaculture 2008. Food and agriculture organization of the United Nations, Rome, 2009. Electronic Publishing Policy and Support Branch. Communication Division. FAO.

Hua, K. and D.P. Bureau. 2009. A mathematical model to explain variations in estimates of starch digestibility and predict digestible starch content of salmonid fish feeds. Aquaculture, 294: 282-287.

Hua, K. and D.P. Bureau. 2009. Development of a model to estimate digestible lipid content of salmonid fish feeds. Aquaculture, 286: 271-276.

Hua, K. and D.P. Bureau. 2010. Quantification of differences in digestibility of phosphorus among cyprinids, cichlids, and salmonids through a mathematical modelling approach. Aquaculture, 308: 152-158.

Hua, K. and D.P. Bureau. 2012. Exploring the possibility of quantifying the effects of plant protein ingredients in fish feeds using meta-analysis and nutritional model simulation-based approaches. Aquaculture 356-357: 284–301.

Hua K., Birkett S, de Lange C.F.M, and Bureau D.P. 2010. Adaptation of a non-ruminant nutrient-based growth model to rainbow trout (*Oncorhynchus mykiss*). *Journal of Agriculture Science* 148 17-29.

National Research Council (NRC), 2011. ***Nutrient Requirements of Fish and Shrimp***. National Academy Press, Washington, DC.

Tacon A.G.J. 2004. Estimated major finfish and crustacean aquafeed markets: 2000 to 2003. International Aquafeed 7 37-41.