MAXIMIZING THE VALUE OF FEED INGREDIENTS IN AQUAFEEDS

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Introduction

Aquaculture is one of the world's fastest-growing sectors of the production of food animals. Aquaculture production is expected to increase by 47% during the period from 2011 to 2030 (World Bank, 2013). In 2018 global aquaculture production reached an all-time high of 114.5 million metric tons (FAO, 2020). In order to maintain the high production of farmed aquatic animals the demand for high-quality formulated feeds, and the ingredients from which they are made, will also rise. Ingredient prices are expected to remain high.

Feed cost often accounts for more than 50% of production costs in aquaculture (Rana *et al.*, 2009). As feed cost is a critical factor involved in the success or failure of individual aquaculture operations, and the industry overall, it is important to maximize the value of feed ingredients in formulated feeds. This paper presents a discussion of a number of considerations that should be taken into account in order to use ingredients in a cost-efficient manner.

Nutrition and Formulation Concepts That Affect the Value of Ingredients

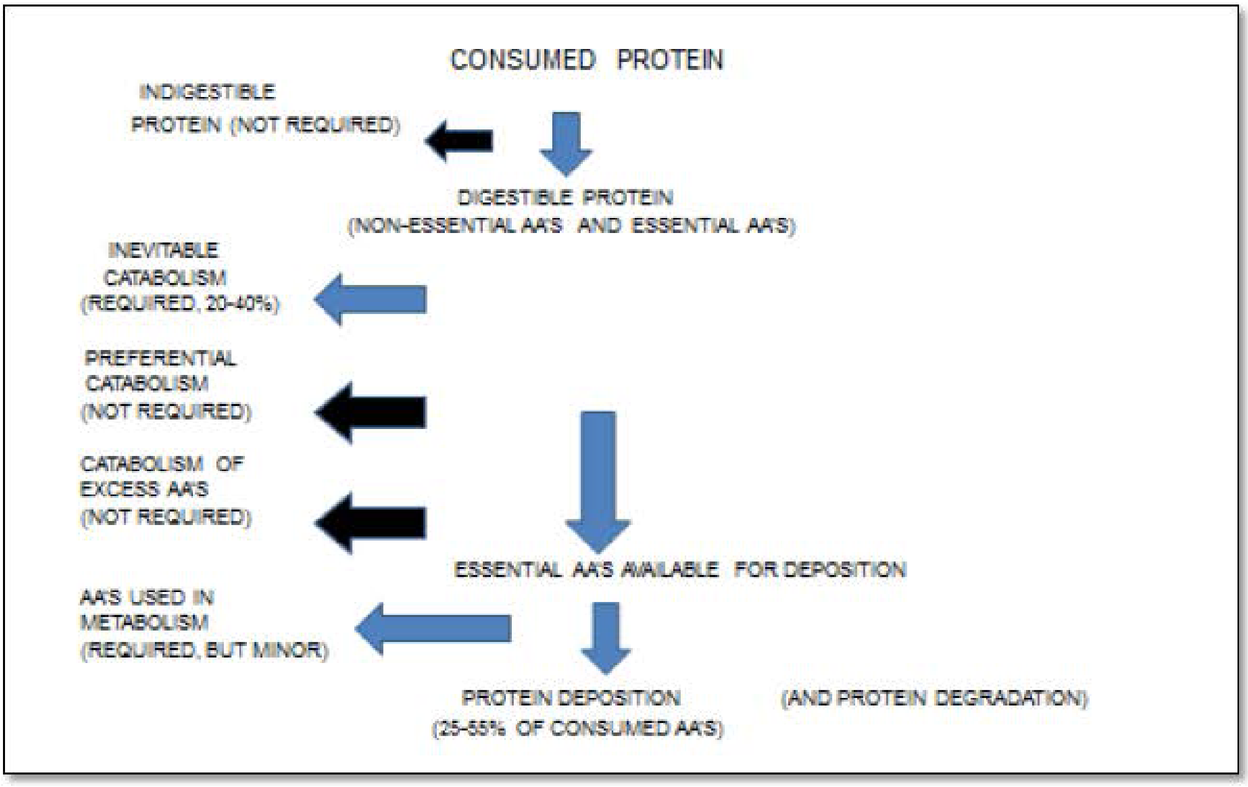
In order to maximize the value of ingredients used in aquafeeds, it is important to understand some basic differences between feeds formulated for aquatic animals and those formulated for livestock and poultry. Fish eliminate nearly 85% of their nitrogenous wastes as ammonia directly into the water across their gills (Kaushik and Cowey, 1991), whereas livestock and poultry have to first combine their nitrogenous wastes into urea and uric acid, respectively, in order to excrete them safely from their bodies. Aquatic animals are neutrally buoyant because the water helps to support their body weight, whereas livestock and poultry have to expend energy to counteract the effects of gravity. Swimming is an energy-efficient means of locomotion when compared to the movements available to terrestrial animals and poultry. Fish and crustaceans are poikilothermic and do not have to expend energy to maintain body temperatures at constant levels as do livestock and poultry. The differences between fish and terrestrial animals in the energy needed to carry out the basic life processes discussed above, combine to make the energy requirement of fish considerably lower than the energy required by livestock and poultry.

Fish can utilize protein efficiently, and as mentioned above, they can easily eliminate the nitrogenous wastes from their bodies across their gills. Livestock and poultry, however, have limits to the amount of protein that they are able to process. For example, an excess of protein in poultry diets will result in mortality. Therefore, fish and shrimp require higher levels of protein in their diets than do livestock and poultry.

The higher percentage of protein in aquafeeds makes this nutrient proportionally more important to the overall nutrition of fish and crustaceans than it is to livestock and poultry. Protein is considerably more expensive than are carbohydrates and lipids. Therefore, in order to maximize the value of feed ingredients in aquafeeds, it is important to optimize the utilization of protein.

An understanding of the fate of consumed protein is necessary to optimize its use in formulated aquafeeds. The utilization of ingested protein is outlined in Figure 1. Digestible protein is broken down into essential and non-essential amino acids, which are absorbed across the digestive tract lining and used in a number of metabolic processes or are deposited as protein in the body of the fish or shrimp. Protein that is not digested is excreted in the feces. Some of the digested amino acids are used in the process of inevitable catabolism. This process oxidizes the amino acids and captures some of the available energy contained in their chemical bonds. Inevitable catabolism results from the cellular catabolic systems that cannot be turned off. The amount of amino acids used in inevitable catabolism can be 20-40% of digestible amino acids (NRC, 2011). Preferential catabolism is the process whereby amino acids are preferentially catabolized to supply energy in diets where non-protein energy sources are insufficient to supply the energy needs of the animal. Essential amino acids are required in specific proportions in order to build the new proteins to be deposited as body protein.

Figure 1. Flow chart of the fate of consumed protein in fish and crustaceans (adapted from NRC, 2011)



Once all of the first limiting essential amino acid in the amino acid pool has been combined with other amino acids to construct new protein, the remaining essential amino acids are in excess of the needs for new protein formation, and will be catabolized for energy. Some of the essential amino acids remaining after those used in catabolic systems will be used in non-structural compounds; such as: coenzymes, metabolic intermediates, neurotransmitters, hormones, or biogenic amines. Essential amino acids and non-essential amino acids derived from dietary or synthetic sources remaining in the pool will be deposited as new protein in the animal's tissues. The deposition of amino acids as body protein ranges from 25% to 55% of total consumed amino acids (NRC, 2011).

In addition to the above processes, body protein is continually being built up and degraded. Clearly, the use of protein and the deposition of amino acids as body protein are dynamic processes.

Some of the processes outlined in Figure 1 are inevitable or required metabolically for the healthy functioning of the organism (blue arrows). Others are affected by the composition of the diet (black arrows) and can therefore be manipulated by nutritionists in order to maximize the value of feed ingredients.

Minimizing the amount of indigestible protein in a formulated diet is an obvious means of increasing the value of ingredients. Protein that is not digestible, and is excreted in the feces, contributes to the eutrophication of the culture environment and receiving waters of the effluent. It is also not available to the fish or shrimp for use as an energy or amino acid source. Feed ingredients should be selected not only for their protein and amino acid content, but also according to their digestibility by the species the feed is being formulated for. Table 1 contains the protein digestibility values of five selected feed ingredients by some farmed aquatic species.

The table demonstrates that there is a wide range of digestibility values for certain ingredients. The reason is that there are a number of different methods used to measure digestibility and each has inherent errors, which are exacerbated by the need to conduct digestibility studies in the water. Hydrolyzed feather meal has lower protein digestibility than the other sources of protein such as, corn gluten meal, fishmeal, and soybean meal, so feather meal should be used conservatively.

Table 1. Protein digestibility of selected feed ingredients by rainbow trout, channel catfish, Nile tilapia, and marine shrimp (NRC, 2011)

Ingredient	Rainbow Trout	Channel Catfish	Nile Tilapia	Marine Shrimp
Corn Gluten	92-97%	---	89-97%	59%
Feather-Hydr	77-87%	74%	79%	64%
Fish-Menhaden	86-90%	88%	85%	84-89%
Soybean Meal	90-99%	93%	87-94%	89-97%
Wheat Midds	68-91%	72%	75%	81%

As protein is built from amino acids, a comparison of digestible amino acids of different ingredients goes further in providing information that allows nutritionists to increase the value of their ingredients. Digestible lysine in hydrolyzed feather meal (1.5%) is about one quarter of that of soybean meal (5.5%) on a percentage of protein basis (IAFFD, 2020). Digestible methionine in feather meal (0.5%) is less than half the amount of digestible methionine in soybean meal (1.2%). Clearly, an evaluation of the cost per unit of the most limiting essential amino acids will lead us to better use of ingredients in aquafeed formulations.

The catabolism of excess amino acids uses protein to generate utilizable energy. "Ideal protein", meaning a balance of amino acids in a diet that exactly meets the requirements of the species in question, is a concept that can be used to reduce the catabolism of amino acids. Table 2 lists the essential amino acid requirements of four freshwater fish species. The amino acids in "ideal protein" would match the profile listed below each species (NRC, 2011). It is not generally achieved in practical diets. However, approaching "ideal protein" will reduce the amount of excess amino acids that are catabolized for energy, and therefore will improve the value of feed ingredients. The utilization of crystalline amino acids can help to approach ideal protein profiles in practical diets.

One of the objectives of the nutritionist is to supply enough well-balanced protein in order to support maximum protein deposition. It is possible to reduce preferential catabolism by supplying sufficient non-protein energy, so that fewer dietary amino acids are catabolized to meet the energy requirement of any particular aquatic species. However, if an excess of digestible energy is available in the diet, compared to the amount of digestible protein, the excess energy will be converted to fat and deposited in the fish. It is important to distinguish between net protein utilization (the amount of ingested protein deposited as protein and fat) and net protein deposition (the amount of ingested protein that is deposited only as protein). We maximize the net protein deposition, and minimize preferential catabolism, by managing the proportion of digestible energy (DE in kcal/100 g) to digestible protein (in %) in the diet. Feeding a diet with a low value of DE/DP (7.5-8) will produce lean fish. Medium values of DE/DP (8.5-9) will produce some, but not excessive, fat deposition. And DE/DP values higher than 9 will produce fatty fish. To maximize the value of our feed ingredients, along with maximizing protein deposition, the objective is find the "sweet spot" between supplying enough non-protein energy to "spare" protein for growth, but not too much energy which will lead to excessive fat deposition (Figure 2).

Table 2. Essential amino acid content of soybean protein and the essential amino acid requirements (% of protein) of rainbow trout, channel catfish, blue tilapia, and common carp

Amino Acid	Soybean Protein	Rainbow Trout	Channel Catfish	Blue Tilapia	Common Carp
Arg	7.4	5.7	4.3	4.2	4.3
His	2.5	2.5	1.5	1.7	2.1
Iso	5.0	2.6	2.6	3.1	2.5
Leu	7.5	4.1	3.5	3.4	3.3
Lys	6.4	6.0	5.1	5.1	5.7
Met & Cys	3.1	3.0	2.3	3.2	3.1
Phe & Tyr	8.3	5.3	5.0	5.7	6.5
Thr	3.9	2.4	2.0	3.7	3.9
Try	1.4	0.6	0.5	1.0	0.8
Val	5.1	3.5	3.0	2.8	3.6

Figure 2. Management of non-protein energy and the DE/DP ratio will maximize net protein deposition while minimizing preferential catabolism

Along with nutritional factors in the diet that affect the efficiency of protein deposition, the amount of feed fed to fish also affects protein deposition. It has been shown that protein deposition is reduced at high feeding rates whereas lipid deposition does not level off at high feeding rates (NRC, 2011). A good feeding program will balance the amount of feed needed for acceptable growth as well as efficient protein deposition. Extruded, floating feed is a good tool to help visually estimate satiation feeding level, and to then calculate feed rations that are approximately 10% lower than the satiation level, to obtain optimum feed conversion ratios (FCR).

Manufacturing Concepts That Affect The Value Of Ingredients:

Shrink, in a feed-milling context, is defined as loss of materials during manufacturing (AFIA, 2005). The form of loss can be dust, theft, moisture, or pest damage. Shrink is measured as the difference in weight of feed ingredients entering the plant minus the weight of finished product leaving the plant. Shrink is composed of feed ingredients that were purchased at a high price, but were not incorporated into shipped feed. Clearly, significant shrink contributes to the inefficient use of feed ingredients, and conversely, reducing shrink will help to maximize the value of feed ingredients. Shrink can best be reduced through three processes: ingredient receiving, moisture control, and an integrated pest management (IPM) program.

The receiving station of feed mills is where the majority of shrink is generated. As either sacked or bulk ingredients are poured from their transportation container into the receiving system of the feed mill, small particles float away as dust. It may not seem like much, but a one percent loss of dust can mean losses in the hundreds of thousands of dollars per year in a large feed mill. One of the best ways to reduce loss at the receiving station is to install vacuum systems at the dump station. The dust is sucked up and recovered in a cyclone. Leaking equipment is another source of dust loss. Leaking equipment should be repaired quickly.

Moisture loss is another source of shrink. If feed ingredients enter the feed mill at a higher average moisture than the average moisture of finished feeds that are shipped, there will be shrink. The moisture level of feed ingredients, mash, and pelleted feeds can change as these materials pass through the feed mill due to evaporation, water addition, steam application, and drying. It is important to monitor the moisture levels of incoming ingredients, mash in the mixer and conditioner, and pellets in the dryer and cooler. Appropriate amounts of moisture should be added, if necessary, so that the final product has approximately 10-11% moisture. Machinery should be adjusted, if necessary, so that feed is not excessively dried. In particular, the moisture level of the mash in the pre-conditioner is critical to moisture control and also to the quality of the finished product. The mash leaving the conditioner should have approximately 14-17% moisture if it is to be pelleted or 25-27% moisture if it is to be extruded. Lower amounts of moisture than those listed here can lead to poor quality feed as well as unacceptable moisture loss.

Feed ingredients consumed by pests contribute to shrink, as well as materials that have to be discarded due to damage by pests. An integrated pest management (IPM) program is required to reduce shrink caused by pests. Most loss and damage of ingredients in feed mills is caused by insects, rodents, and birds. Inspection and sampling of incoming ingredients as well as stored ingredients is a critical component of the IPM program. Incoming ingredients infested with insects can either be rejected or fumigated. Early discovery of stored ingredients infested with insects allow treatment and recovery of much of the materials, as well as limiting the spread of the infestation to other lots of ingredients.

Sanitation of the outside grounds as well as inside of the feed mill cannot be stressed enough. Brush and debris outside of the feed mill can harbor insects, birds, and rodents.

Spilled ingredients and feed inside the feed mill attract pests. All entry points to the mill should be secured against pests. Windows and spaces between roof and walls should be screened. Doors should be closed as much as possible, especially at night. Plastic strips at doorways help to keep pests out of the mill. Fumigation and traps are effective tools for treatment.

Nutritionists take into account many nutritional and cost factors to design optimum formulations for a given species. If the manufacturing process is not strictly controlled, and the final feed product does not conform to the original formulation, then the feed ingredients will not be efficiently utilized. There are four processes within manufacturing that can contribute to achieving formulated nutrient levels in the final product: Ingredient sampling and analysis, adjustment of mix sheet on manufacturing day, lot tracking, and post pellet/extrusion liquid coating.

Sampling of feed ingredients must be done correctly so that the relatively small sample is representative of the large lot of material. If the sample is not representative of the total shipment of feed ingredient, the nutrient values analyzed by the laboratory will mislead the nutritionist into formulating inefficient feeds. A sampling program must be designed to take into account different types of ingredients and different shipping containers, such as sacks, liquid tanks, and trucks carrying dry, bulk ingredients.

Nutritionists formulate diets based on the nutrient analyses of specific lots of ingredients. Often those original lots of ingredients have been used up prior to manufacturing day and other lots must be substituted. In that case, the analyzed nutrient levels of the new lots of ingredients must be used to adjust the mix sheets so that the same amount of nutrients is added to the mixer even though the nutrient characteristics of the ingredients are different from the original ones. For example, more kilograms of a 63%-protein fishmeal must be added to the mix than the amount of a 65%-protein fishmeal in the original formulation, in order to maintain the same amount of fish protein in the diet.

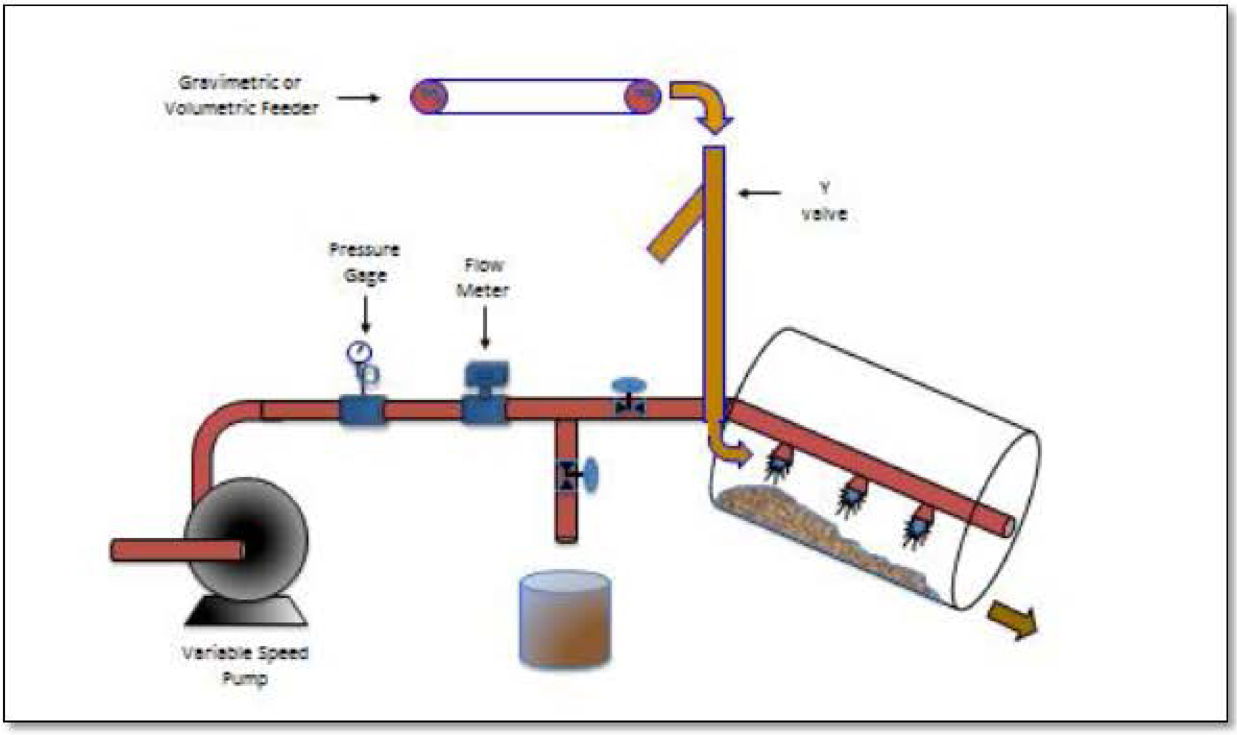
Lot numbers must be used to identify lots of specific ingredients as they are sampled, analyzed, formulated, and added into the mixer. This is essential so that ingredients are used when they are fresh and so that mistakes are reduced in the weighing of ingredients into the mixer.

Sometimes error at one of the last steps in the manufacturing process causes the nutrient characteristics of the final feed to deviate from the original formulation. This step is the application of liquids, usually oil, to the feed after it has been pelleted, dried, and cooled. Accurate liquid coating depends on precise adjustment of the flow of dry pellets and the corresponding flow of liquid to the sprayer. Some equipment includes automatic methods to adjust these flows, but it is still worthwhile to calibrate the machinery. If appropriate valves are built into the system, periodic checks of actual pellet flow and liquid flow can be confirmed (Figure 3).

Conclusions

The value of feed ingredients can be maximized in aquafeeds by manipulating the nutritional factors that maximize protein deposition and by minimizing the loss of ingredients in the manufacturing process. Controlling the feeding rate of aquatic animals and making sure that the final feed conforms to the original formulation also contribute to the efficient use of expensive feed ingredients.

Figure 3. Liquid coating system with valves in the dry feed and liquid lines that can be used to calibrate the flow rates



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.

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