Mineral supplementation in aquaculture

By Dr. Thomas Wilson

While there is substantial knowledge concerning the mineral requirements of land animals, there is little known about the trace mineral requirements for fish and shrimp. This is primarily due to the difficulties of conducting research in marine species. However, mineral supplementation of all aquaculture feeds is recommended to maintain sufficient whole-body and tissue levels of important trace minerals such as zinc, manganese, iron and copper. This often raises the question of whether to use organic or inorganic mineral sources for supplementation. There is mounting evidence demonstrating the benefits of organic trace minerals, instead of inorganic forms in aquaculture feeds. The major reasons are detailed in this article.

Why use organic minerals in aquatic animal feeds?

Absorption of minerals is limited because of antagonisms and interactions with feed components. Formation of insoluble complexes, or those that are too large to be absorbed when combining with other components in the feed, limit bioavailability of minerals. In addition, some minerals compete for the same transporters and metabolic processes for absorption, which limits the availability of these minerals or vitamins for the animal. Inorganic mineral forms (*e.g.* sulphates) are very weakly bound, and are therefore free to interact. Organically bound minerals are not reactive, which will prevent complex formation. In addition, competition for absorption can be avoided partly by absorption using the pathway(s) of the ligand.

Prevent Over-Supplementation of Trace Minerals

Environmental regulations in many countries are now setting controls on effluents from aquaculture, including limits on the phosphorus content of feed. There are concerns that excess minerals released by farm animals into the environment are a source of pollution. Copper and zinc are two minerals that are often used in excess in feed for land animals, as replacements for antibiotic growth promoters (AGPs). No such benefits have been shown for aquatic animals, but excessive use of minerals, or use of mineral supplements with poor bioavailability is being questioned. In fact, there may be more scrutiny of aquaculture-related industries, because excess or unabsorbed minerals in feed are often excreted directly into lakes, rivers and other waterways that provide our drinking water.

With feed regulations in many European countries limiting the phosphorus content of feed, it is important that the phosphorus contained in raw materials is fully utilized. Interactions between inorganic minerals and added feed phosphates can interfere with absorption of the phosphate by the minerals due to competition for binding sites and enzyme transporters. Ashmead and Zunino (1993) showed years ago that bi-glycinate chelated minerals have their own means of uptake by an organism, and largely by-pass conventional transport mechanisms, limiting competition between phosphate and trace minerals.

Avoid Interaction with Bone Ash

Today, the sustainability of aquaculture farming and feed (fishmeal reduction and

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makes sense

substitution), is pushing the feed industry towards using as much seafood processing waste as possible. The use of typical "brown" fish meals is seen as largely unsustainable, and the feed industry is moving more and more to using marine co-products from seafood processing industries, such as fishmeal made from tuna canning waste streams, the so called "white" fishmeal made from fish filleting waste, and fishmeal made from surimi process waste.

These kinds of fishmeal have high bone ash content, making them high in largely indigestible tri-calcium phosphate. Feed made with these types of fishmeal is often found to have low availability of trace minerals, due to interference with absorption caused by the tri-calcium phosphate. As the percentage of this type of fishmeal increases in feed formulations, the bioavailability of inorganic forms of copper, iron, manganese and zinc becomes more uncertain. Sugiura et al. (2000) added purified defatted fish bone ash to rainbow trout feed, and reported that digestibility of iron became negative at any level of supplementation, an indication of the big impact bone ash can have on trace mineral availability. Another trend is the use of animal by-product meals to replace fishmeals. Here also, the high bone ash content has been shown to interfere with trace mineral absorption.

Supplying trace minerals in the form of a glycinate (minerals bound to the amino acid, glycine) sidesteps all of the issues of interference caused by bone ash and high phosphorus levels. The stability of the organic bond is essential to prevent interactions and competition, demonstrating the added value of an organic trace mineral. In different trials, the superior stability of a specific glycinate[1], has been shown in water, at different pH, in premix, in pelleted feed and even in the presence of known antagonists and in acidic liquid feed.

Reduce Oxidation of Important Nutrients

Seafood grown in aquaculture farms is expected to be as attractive, wholesome and nutritionally complete as wild-caught seafood. The market and marketing of farmed Atlantic salmon is a perfect example.

Consumers expect farm-raised salmon to have the same attractive orange-red color as wild salmon. This is achieved by adding synthetic or natural astaxanthin to feeds. Astaxanthin is one of the most powerful anti-oxidants known, but it is subject to destruction by oxidation caused by inorganic trace minerals.

Farm-raised salmon is also expected to have the same levels of beneficial omega-3 fatty acids (primarily EPA and DHA) as wild fish. Torstensen et al, fed several trace minerals to Atlantic salmon smolts and reported reduced levels of plasma lipids from high dietary copper intake. Desjardins et al. (1987) showed that increasing iron from iron sulphate ($FeSO_4$) in diets increased the oxidation of lipids in the diet.

[1] B-TRAXIM® 2C, Pancosma SA, Switzerland

A reasonable shelf life from farm to table is another expectation. Oxidation occurring in seafood after harvest creates off-flavours, and causes breakdown of pigments like xanthophylls and carotenoids, resulting in unwanted discolouration.

Moreover, the European Union bans the use of antibiotic growth promoters (AGPs). The maximum health of fish can be supported by adding functional plant extracts that often have a strong anti-oxidant component, contributing towards their effectiveness. Inorganic forms of copper and iron are known to be strong “pro-oxidants”, counteracting plant extracts in the feed and adding oxidative stress.

Substituting inorganic minerals with organic trace minerals may reduce the oxidative effects of minerals in premixes. This limits oxidation of important vitamins for animal health and growth and oxidation of feed during feed manufacturing and storage. Furthermore, organically bound minerals, may prevent oxidative damage to intestinal cells during digestion, and oxidation in tissues after absorption. This may reduce free radicals and other reactive oxygen species (ROS) in meat, to improve quality and extend shelf life.

Protect Vitamins
Aquaculture feed provides concentrated protein and lipid content. In addition, supplementation of vitamins and minerals tends to be quite high, and therefore expensive. At the same time, manufacturing methods for aquaculture feed utilize high temperatures, and loss of vitamins can be excessive. The aquafeed industry uses heat resistant coated, encapsulated and protein-bound forms of vitamins, which are the most expensive forms on the market. Oxidation during production and pelleting always causes loss of vitamins, which has to be compensated for, usually by over-supplementation. Anything that can be done to preserve these vitamins from being damaged will allow lower dosages to be used, thus reducing costs.

Shurson et al. (2011) showed significant reduction of the vitamin levels in feed premixes containing inorganic mineral sources, while using organic trace minerals clearly decreased the reduction of vitamin levels.

Interactions with Phytase
While most vertebrates have acidic stomachs, and adult tilapias are known to have a stomach pH as low as 1.5–2.0, fish species in the Cyprinidae family (e.g. carps) are stomachless, and do not have an acidic pH anywhere in the gut. Also crustaceans, like marine shrimp do not have a conventional stomach. The functions of the stomach in shrimp are replaced by digestive secretions in the midgut gland (also known as hepatopancreas), with digestion occurring at near neutral pH. While red-blooded vertebrates rely on iron-haem in hemoglobin to carry oxygen, crustacean blood is clear to blue coloured, and relies on heamocyanin-bound copper to transport oxygen. Consequently, crustaceans have a high requirement for dietary copper (20-53 mg Cu/kg feed is recommended).

As the use of feed enzymes becomes more widespread in aquaculture feeds, questions have arisen regarding the effectiveness of enzymes at near neutral pH, and also whether enzymes are effective in animals such as crustaceans that have a fast gut passage time (maximum 4 hours for marine shrimp).

When phytase is used, it can release a maximum of six phosphorus atoms per phytate molecule. The release of this phosphorus is interesting and cost effective, because it reduces the need to add feed phosphates.

Pang and Applegate (2006) have shown with *in vitro* experiments that inorganic copper suppresses the hydrolytic activity of phytase enzymes at pH 5.5 and 6.5, but that tri-basic copper chloride and copper lysine did not suppress activity much. There is a lot of interest in using phytase enzymes with crustaceans, but this research suggests that phytase activity might be inhibited by high levels of inorganic copper. In another study, Mainz et al. (1999) did not investigate copper, but looked at several other macro and trace minerals and their effect on phytase. They reported that zinc inhibited phytase activity in solution at a concentration of only 0.053 millimole, equivalent to a low level of zinc in feed.

Replacement of inorganic minerals with chelated organic minerals reduces interactions between minerals and other feed components during digestion, and would not impact phytase activity. The use of organic trace minerals is therefore recommended over inorganic sources in phytase-supplemented feeds (intended for stomach-less fish and crustaceans).

Conclusion

The aquaculture feed business is moving towards sustainability, and replacing fishmeal is a high priority. While fishmeal is considered to be the best protein source for fish, it is not always the best source of trace minerals. All of the alternatives to fish protein, animal or plant based, have physical or chemical characteristics that impact trace mineral utilisation negatively. However, the aqua feed industry is limited in choice.

Successful fishmeal replacement will depend on the use of organic minerals. Understanding more about the role of trace minerals in aquatic animals and the future challenges of aquaculture, makes it clear that mineral supplementation can only be effective using organic sources.

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