Benefits of Including Krill Meal in Shrimp Diets

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Overview

Antarctic krill *Euphausia superba* is one of the most abundant species on earth, with an estimated biomass of around 500 million tons. They are shrimp-like in appearance, with an average body length of only 5 cm, with big black eyes and a reddish, semi-transparent shell (Fig. 1). They live in huge swarms in the icy cold waters of the Southern Ocean, where they are harvested from the wild.

The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) restricts harvesting to a specific region in the Southern Ocean (Area 48) and to an annual krill harvest of 1 percent of the total biomass. (The precautionary level for other fisheries is 10 percent of the total biomass.) Aker BioMarine's krill fishery has been certified by the Marine Stewardship Council as sustainable and 100 percent traceable.

Krill meal is prepared from an aqueous extract of ground whole Antarctic krill that is cooked and dried, resulting in a brownish-orange powder containing around 60 percent protein with a nutritionally well-balanced amino acid profile (Fig. 2). Krill meal is a sustainable source of protein, omega-3 phospholipids, feed attractants and astaxanthin. The beneficial effects of incorporating krill meal into shrimp diets are reviewed in this article.

FIGURE 1. *Antarctic krill* Euphausia superba.

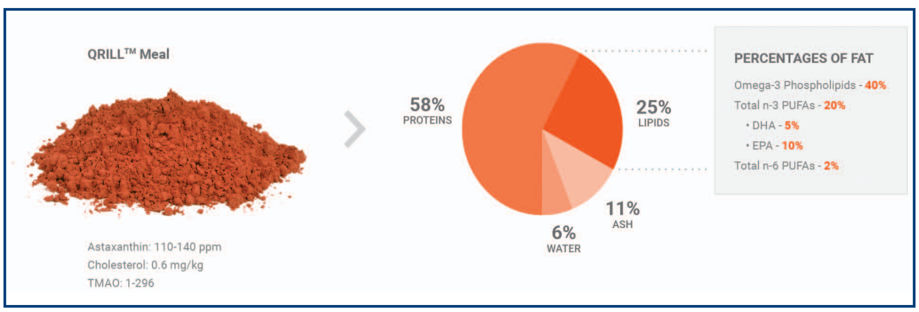

FIGURE 2. *Krill meal (QRILLTM) composition has a high content of protein, omega-3 phospholipids and astaxanthin. Abbreviations: DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; n-3 PUFAs, omega-3 polyunsaturated fatty acids; TMAO, trimethylamine oxide.*

FIGURE 3. Litopenaeus vannamei *(left) and* Penaeus monodon *(right).*

Krill Meal for Shrimp Aquaculture

Commercial shrimp farming has grown steadily to contribute almost two-thirds of the world's marine shrimp production. Farming concentrates on penaeid shrimp, mainly black tiger shrimp *Penaeus monodon* and whiteleg shrimp *Litopenaeus vannamei*, known for their good adaptation to confinement and rapid growth (Fig. 3).

Continued growth of shrimp farming and the change from low-intensity, small-scale to high-intensity, commercial farming (Fig. 4) has increased the need for sustainable protein sources in shrimp feeds. However, fishmeal supplies from wild-caught forage fisheries are not likely to increase from the current harvest level (Fig. 5).

One way to address the high demand for fishmeal has been to replace it in shrimp feeds with soybean meal, which increases

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the cost-effectiveness and sustainability of commercial shrimp feed. However, soybean meal has a different nutrient and amino acid profile than fishmeal. Reduced palatability and anti-nutritional factors causing low digestibility can lead to impaired culture performance of shrimp. Moreover, fishmeal is of significant dietary value to shrimp as a source of minerals and omega-3 long-chain fatty acids that are absent in soybean meal. In contrast to marine lecithins that contain omega-3 fatty acids in phospholipid form, soy lecithins are particularly rich in the omega-6 fatty acid, linoleic acid.

Krill meal is rich in chitin from the exoskeleton and soluble compounds such as trimethylamine oxide, free amino acids and nucleotides that may act as feeding stimulants (Table 1). Feeding stimulation by partial replacement of fishmeal by krill meal in diets leads to increased growth of shrimp, which also occurs in situations of feeding depression (e.g. high plant-based diets) or stress conditions (e.g. change in salinity or temperature). Krill meal is also used in functional fish feeds to increase growth and fillet quality. Salmon fed a diet that included krill mill had reduced mortality and heart pathology during viral infection. Further study is needed to determine if krill meal has a similar effect on the immune system of shrimp.

Krill meal also contains around 25 percent lipids that include a high amount of phospholipids (around 40 percent), omega-3 fatty acids (EPA and DHA) and astaxanthin esters. The antioxidant astaxanthin provides pigmentation and is known to have anti-inflammatory properties by scavenging free radicals, thereby counteracting oxidative stress and damage to proteins, lipids and DNA (Sies 1993).

In fish oils, the omega-3 fatty acids are bound to triglycerides; in krill meal, these fatty acids are bound to phospholipids (Fig. 6).

FIGURE 4. *Intensive grow-out pond for shrimp in Indonesia using paddlewheel aerators.*

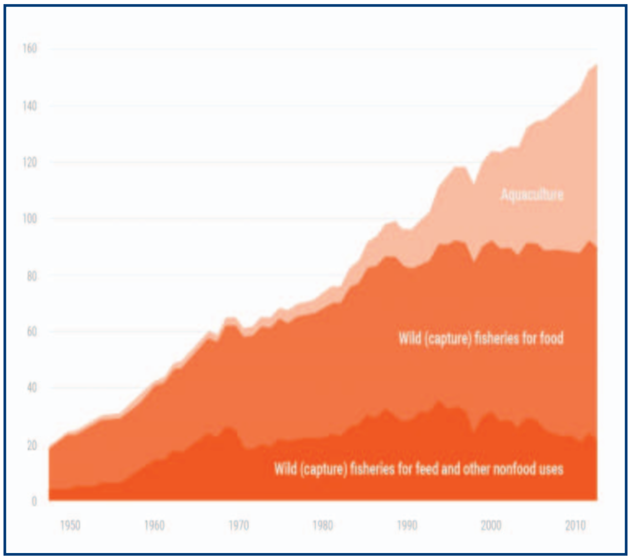

FIGURE 5. *The amount of wild harvested forage fish for fishmeal has remained constant since the 1990s, while aquaculture production has been increasing steadily.*

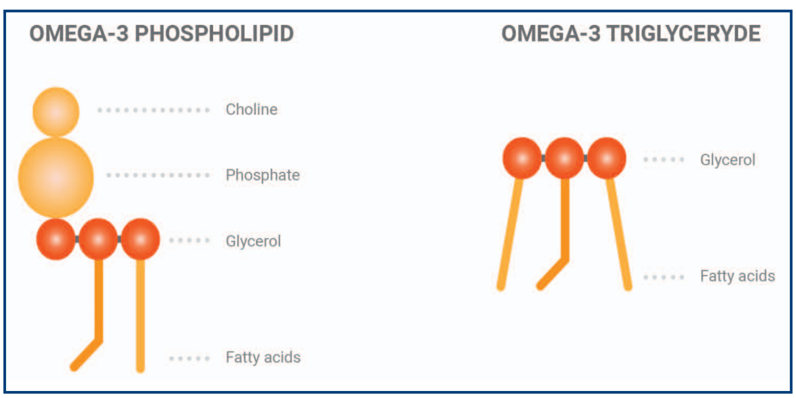

FIGURE 6. *Omega-3 fatty acids can be in phospholipid or triglyceride forms.*

The structural difference in presenting omega-3 fatty acids might be of relevance to shrimp health because omega-3 fatty acids that bind to phospholipids, the building blocks of all cells, are more effectively incorporated into tissues and cells than omega-3 bound to triglycerides (Graf *et al*. 2010, Liu *et al*. 2014, Rossmeisl *et al*. 2012, Wijendran *et al*. 2002).

The main phospholipid in krill meal is phosphatidylcholine (Phleger *et al*. 2002, Tou *et al*. 2007), which not only delivers omega-3 fatty acids, but also choline. Choline is an essential vitamin-like nutrient that is crucial for cellular functions such as neurotransmission and osmoregulation (Food and Nutrition Board 1998). Choline must be added to shrimp feed unless sufficient phosphatidylcholine is present (Gong *et al*. 2000).

Phospholipids might also help overcome the limited ability of shrimp to make endogenous phospholipids (Kanazawa *et al*. 1985). Shrimp depend on dietary phospholipids, especially in larval and juvenile stages, for building cell membranes, lipid digestion and transport in plasma lipoproteins, and cell signaling. Phospholipids are particularly abundant in the hepatopancreas. Sufficient energy stored in the hepatopancreas is important for shrimp growth and improves shrimp's ability to resist to stressful conditions (e.g. low oxygen concentration, molting, rapidly changing water temperature or salinity etc.). Dietary phospholipids ensure that sufficient energy is stored in the hepatopancreas and fats can be mobilized for transport to tissues, particularly important to overcome stressful environmental changes (Gong *et al*. 2004).

Cholesterol is also a vital nutrient in shrimp feed, important for membrane function, lipoprotein transport, hormone production and absorption/transport of fatty acids. Cholesterol uptake and distribution in shrimp depends on the availability of phospholipids. Dietary cholesterol levels can be decreased from 0.35 to 0.05 percent when phospholipid levels are simultaneously increased to 5 percent (Gong *et al*. 2000). Almost no dietary phospholipids are needed when cholesterol levels are high.

In short, penaeid shrimp has an inadequate ability to make phospholipids, choline and omega-3 fatty acids. Krill meal delivers protein and feeding stimulants, phospholipids, choline and omega-3 fatty acids in an all-in-one combination in the form of omega-3 lecithins. This blend of factors makes krill meal particularly attractive as a shrimp feed ingredient to improve growth, stress resistance and survival of larvae, post-larvae and juveniles.

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TABLE 1. Characteristics of krill meal that have beneficial effects when incorporated into aquaculture feeds.

QRILL™ characteristics	Results	Benefits
▪ Low molecular weight soluble compounds: **nucleotides** and **amino acids** (e.g. proline, glycine, glucosamine) ▪ High levels of **TMAO**	▪ Improved **feed attractability** and **palatability**	▪ Stimulated **feed intake** ▪ Enhanced **shrimp growth** ▪ Decreased **FCR** ▪ Increased **yield**
▪ **Astaxanthin**, a strong antioxidant and carotenoid	▪ Stronger **immune system** ▪ Increased **pigmentation** ▪ Improved **consumer preference** (visual appearance/flavor)	▪ Enhanced **disease resistance** ▪ Boosted **survival rates** ▪ Improved **product value/marketability**
▪ **Cholesterol** ▪ **Omega-3 fatty acids** ▪ **Phospholipids**	▪ Improved **lipid absorption/transport** ▪ **cell membrane integrity**	▪ Increased **stress tolerance** (e.g. water salinity, low cholesterol, plant-based diets..)

TABLE 2. A summary of studies indicating the benefits of including krill meal in shrimp diets.

Parameters	Explanation	Effects of krill meal/astaxanthin krill oil	References
Cholesterol replacement	Cholesterol is expensive and availability inconsistent. Shrimp have limited ability to make cholesterol and show reduced growth, if insufficient cholesterol is present in the diet.	↑ Growth without dietary cholesterol	Unpublished results
Consumer sensorial preference	Optimizing feed ingredients of diets can affect not only the animal's zootechnical performance, but also the qualitative characteristics of the final product such as color, texture and flavor.	↑ Natural color in end product ↑ Flavor in end product ↑ EPA/DHA content in shrimp tails	Castro et al., 2016 Submitted for publication
Feeding stimulation	Different attractants are used to stimulate shrimp to feed. Krill meal is a chemostimulant that increases the feeding time (not the speed) and thus the amount eaten.	↑ Feed intake ratio ↑ Weekly growth	Derby et al., 2016 Smith et al., 2005
Growth accelerator	A growth factor was found in the insoluble protein fraction of krill meal.	↑ Weekly growth ↓ Feed conversion ratio	Williams et al., 2005
Hypersalinity stress	Osmotic stress leads to slower shrimp growth, poor feed conversion ratio and lower survival.	↑ Growth in hypersaline conditions	Castro et al., 2016 Submitted for publication
Poultry protein diets	Poultry by-product meal is used as replacement for fish meal in some shrimp feed, but palatability and feed intake are challenges.	↑ Palatability ↑ Attractability ↑ Weekly weight gain	Suresh et al., 2011
Plant protein diets	Vegetable-based diets are used as replacement for fish meal in some shrimp feeds because of increasing fish meal prices and market volatility.	↑ Feed intake ↑ Growth ↑ Yield ↑ Final body weight	Sabry-Neto et al., 2016
Sustainability	Historically, fish meal has been the main source of protein in shrimp feed. With reduced wild catch due to over hunting, a new sustainable attractant for shrimp feed is needed.	↑ Sustainability ↑ Fish in the sea ↓ Need for wild caught fish for fish meal	Waite et al., 2014

Study Results of Dietary Krill Meal Inclusion

The effect of inclusion of krill meal on penaeid shrimp performance has been investigated (Cordova-Murueta and Garcia-Carreno 2002, Nunes *et al*. 2011, Sá *et al*. 2013, Smith *et al*. 2005, Suresh *et al*. 2011, Williams *et al*. 2005) and the benefits are summarized in Table 2.

Krill meal as a feeding stimulant

Among different feeding effectors commercially used in shrimp feeds (betaine, hydrolysates, squid and crustaceans), crustacean and krill meal are the most efficient drivers of feed intake in tiger shrimp (Smith *et al*. 2005). Moreover, krill meal increases the number of pellets eaten by whiteleg shrimp in a concentration-dependent manner by promoting longer, rather than faster consumption (Derby *et al*. 2016).

Krill meal as a growth accelerator

Rapid growth is one of the most desirable culture parameters in shrimp farming. High growth rates can improve production efficiency, survival rates and yield. This can be achieved through a shorter culture period and greater crop turnover. "Unknown growth factors" are thought to exist in some protein meals derived from marine invertebrates, such as squid, polychaetes, shrimp, krill and mollusks (Cruz-Suarez *et al*. 1987, Guillaume *et al*. 1989). The growth-enhancing activity is partly explained by the supply of inorganic elements and nutrient balance having positive influence on feed intake. A growth factor is present in the insoluble protein portion in crustacean-derived ingredients (Smith *et al*. 2005, Williams *et al*. 2005). Juvenile tiger shrimp grow 20 percent faster on feeds containing crustacean meal or krill meal (Smith *et al*. 2005), while growth of shrimp increased from 0.58 g/wk with a basal diet to 1.22 g/wk with diets containing krill meal (Williams *et al*. 2005). Krill meal enhances culture performance of juvenile whiteleg shrimp fed a soy protein concentrate-based diet containing only 5 percent fishmeal (Sá *et al*. 2013). A combination of whole squid meal and krill meal at dietary levels starting at 0.5 percent (as is basis) enhances shrimp final body weight. A more pronounced effect is found when incorporation of both feed ingredients sums to 2 percent of the diet.

Krill meal in plant-based diets

While shrimp feed increases production, it is also costly, making up more than 60 percent of the operational costs of shrimp farming. Between 25 and 40 percent of shrimp feed is protein, which has traditionally originated from fishmeal. However, limited supplies and high prices have increased the interest in plant-based protein diets, mainly using soybean meal. These diets often lack palatability and contain anti-nutritional properties that can depreciate shrimp performance.

The minimum inclusion level of krill meal in plant-based feeds to enhance growth is low (Sabry-Neto *et al*. 2016). A dietary inclusion of 1 percent krill meal is sufficient to enhance feed intake, but acceleration of growth, increased yield and a reduction in FCR is only observed at 2 percent inclusion.

Krill meal in animal by-product meal diets

Rendered animal by-products such as spray-dried blood meal, meat and bone meal, poultry by-product meal and hydrolyzed feather meal are also common sources of protein in shrimp feeds. They can be included in shrimp feeds at dietary levels that range from less than 5 to more than 20 percent. Some proteins of terrestrial origin are poor feeding stimulants for juvenile whiteleg shrimp (Nunes *et al*. 2006). Behavioral observations carried out in a Y-maze apparatus indicate that bloodmeal and meat and bone meal can promote some level of attractiveness, but act as a repellent at the time of feed intake (Nunes *et al*. 2006). In diets for blue shrimp *Litopenaeus stylirostris* designed to contain 20 percent poultry by-product meal, feed attraction was improved by including 3 percent squid meal or krill meal. However, feed palatability and shrimp growth was only enhanced when krill meal was used (Suresh *et al*. 2011). Therefore, formulators should be aware of the need to supplement feeds based on a high inclusion of animal by-products with krill meal to account for the poor feeding stimulation caused by feeds containing animal by-product meals as a protein source.

Krill meal as a cost saver

To fully meet shrimp nutrient requirements, feeds must rely on costly ingredients that include fish oil, soybean lecithin and cholesterol, among others. Krill meal at 5 percent can generate a formula cost savings of more than 10 percent without compromising shrimp growth performance (Nunes *et al*. 2011). This was achieved by eliminating the dependence on soybean lecithin and reducing the use of fishmeal, fish oil and cholesterol. Cholesterol can be completely removed from whiteleg shrimp diets when 3 percent krill meal is used in combination with a minimum of 5 percent fishmeal. This generated a formula cost saving of 6.1 percent, while improving shrimp performance parameters such as body weight, survival, yield, feed intake and FCR.

Conclusions

Due to its inherent advantages – i.e. as a feeding stimulant, omega-3 fatty acids bound to phospholipids, highly digestible peptides, naturally pure and stable, sustainably sourced – including krill meal in shrimp feed shows promise to improve shrimp culture performance without adding costs.

In particular, in diets low in fishmeal, krill meal's feed attractants increase palatability and improves growth performance of shrimp. Omega-3 phospholipids present in krill meal assure that fats (cholesterol and triglycerides) are efficiently emulsified and digested, stored in the hepatopancreas and mobilized when needed. Full energy reserves in the hepatopancreas and efficient mobilization ensure the best protection against stress situations.

Key Points

- In shrimp farming, increasing attention is given to Antarctic krill *Euphausia superba*, a shrimp-like swarming pelagic crustacean living in the Southern Ocean, to improve yield and stress resistance without increasing production costs.
- High-protein krill mill is used as a feed additive in diet formulations as an attractant and shrimp growth accelerator.
- Krill meal is a sustainable and pure alternative to fishmeal, consisting of around 11 percent omega-3 phospholipids.
- Shrimp produce phospholipids inefficiently and depend on dietary addition for building membranes, fat storage/transport and resisting to adverse growing conditions.

• Dietary phospholipids increase the transport of cholesterol, triglycerides and omega-3 fatty acids from the digestive tract to the hepatopancreas and through the hemolymph to tissues. Omega-3 phospholipids may improve energy transport and stress sensitivity.

• Feed attractants in krill meal improve growth performance of shrimp fed normal fishmeal-based diets, but also in diets based on plant or animal by-products protein.

Notes

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