The thrill of krill

The benefits to fish and shrimp come from a combination of amino and fatty acids mixed with chitin, astaxanthin, dietary phospholipids, vitamins and other low molecular weight soluble attractants in the diet

By Lena Burri

Seafood contains important nutrients, such as the long chain omega-3 polyunsaturated fatty acids (n-3 PUFAs), eicosapentaenoic acid (EPA) and docosahexaenoic (DHA), which terrestrial animal and plant products typically lack. On top of that, seafood is a rich source of additional nutrients, such as amino acids, vitamins and minerals.

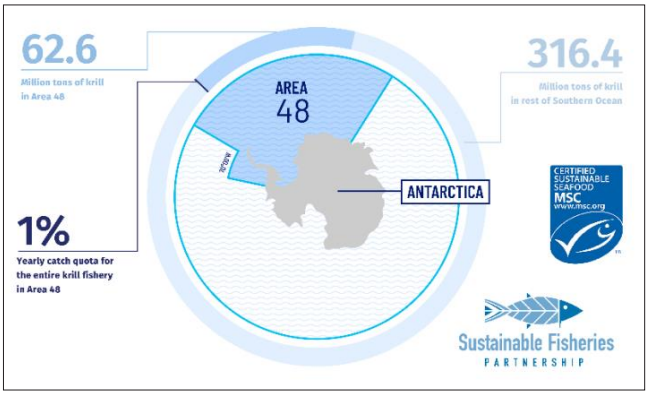
The diet given to farmed aquaculture species must contain all essential nutrients to produce healthy and high quality animal products for human consumption. Krill meal, in addition to being a rich source of protein and lipids, also provides other essential nutrients, such as antioxidants, vitamins and minerals that make it one of the superfoods in the aquafeed sector, known for its high palatability and attractability (Tou et al., 2007).

Antarctic krill

The Antarctic krill (*Euphausia superba*) is found in the Southern Antarctic Ocean. The up to 6cm large krill aggregate in large swarms, where they feed on microscopic algae. Following the saying 'you are what you eat', krill accumulate many of its special biochemical properties from the tiny 'vegetarian' snack. The carotenoid pigment required to synthesise astaxanthin, for example, is first constructed by phytoplankton. Fuelled by sunlight, the photosynthetic plankton also produces significant quantities of triacylglycerol and phospholipids quickly gobbled up by hungry krill (Hamner et al., 1983; Hellessey et al., 2018). Krill are such effective algal planktivores that each consumes up to 20% of their body weight per day. Lacking light in the deep ocean, krill evolved to emit yellow-green light periodically from specific bioluminescent organs distributed across its body.

Sustainable krill biomass

Krill meal is produced from krill caught exclusively in area 48, off the Antarctic peninsula, where the catch is limited to 1% of the total estimated biomass.



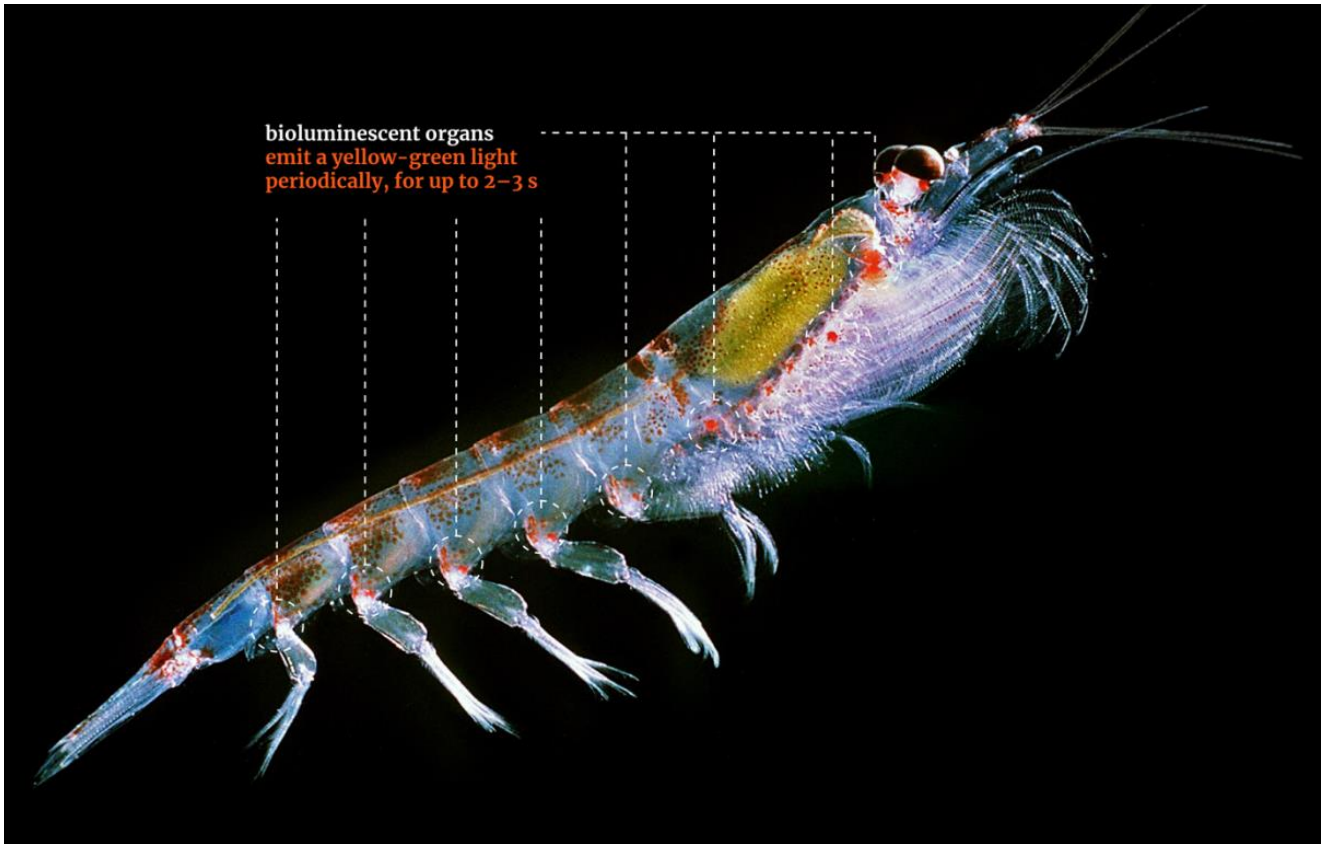


Figure 1. Illuminating the function of bioluminescent organs in krill. Photo by Uwe Kils, licensed under CC BY-SA 3.0.

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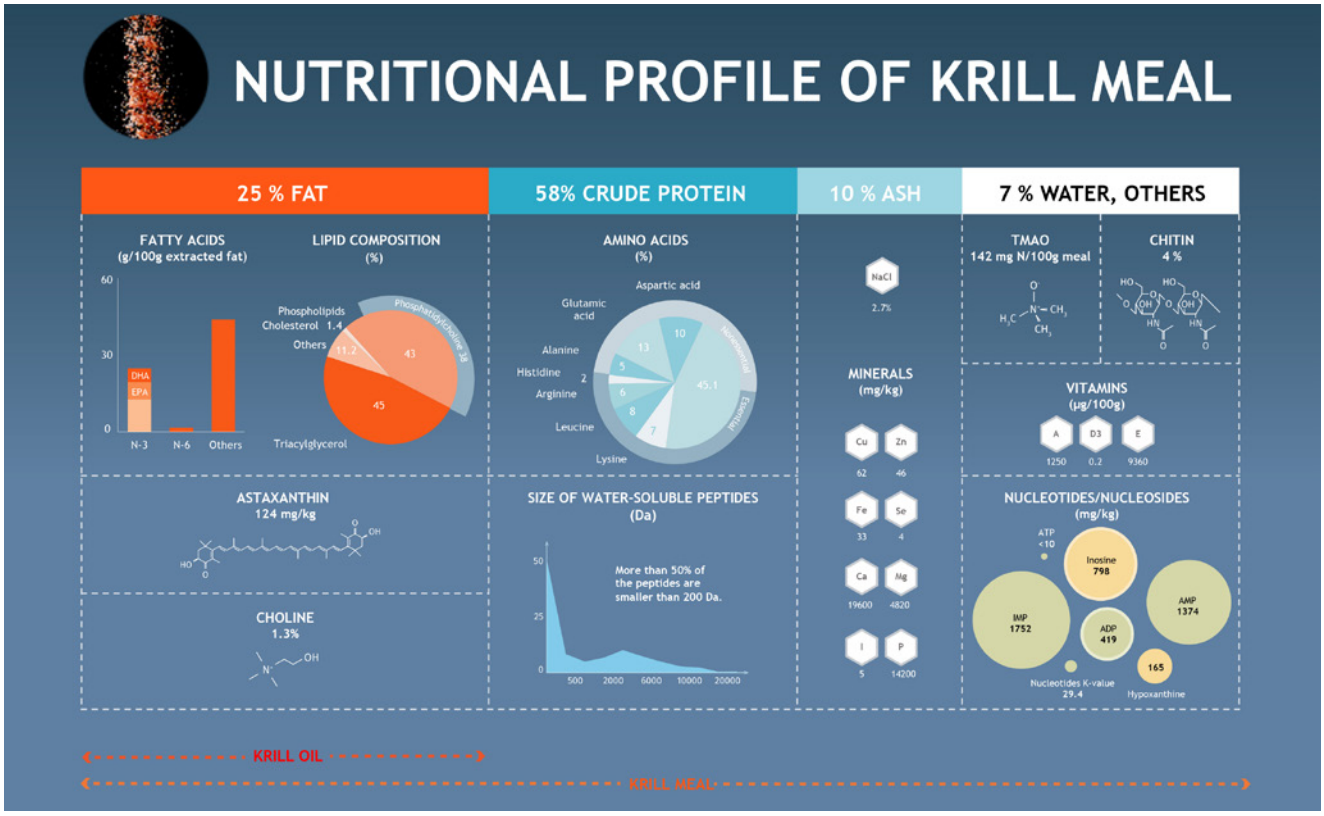


Figure 2. A complete nutritional profile of krill meal including typical values of macronutrients, essential fatty and amino acids, as well as important feed attractants and biochemical components. ADP: Adenosine diphosphate; AMP: Adenosine monophosphate; ATP: Adenosine triphosphate; DHA: Docosahexaenoic acid; EPA: Eicosapentaenoic acid; IMP: inosine monophosphate; TMAO: Trimethylamine N-oxide; K-value represents the ratio of Inosine to Hypoxanthine with smaller values implying increased freshness (Scale example - Sashimi-grade sushi: ~20; commercially available fish: ~30-45).

The estimated biomass has increased from 60.3 million tonnes measured in 2000 to 62.6 million tonnes in 2018/19 according to findings from the Commission for Conservation of Antarctic Marine Living Resources (CCAMLR). The conservative catch quota and trends in biomass explain why krill stocks count amongst the best managed and underutilised marine resources to date. Aker BioMarine's krill harvesting is also notable for near-zero by-catches, fully transparent operations and the Marine Stewardship Council (MSC) certification. In 2020, the krill fishery received an "A" rating by the Sustainable Fishery Partnership with a biomass that is rated "in very good condition."

Krill meal is the superfood amongst animal feeds

The realisation that many fish stocks are overexploited has caused a shift away from including fishmeal in animal feeds. However, the rich nutritional profile of krill meal makes this product an ideal supplement to fill the nutritional gaps of more sustainable plant-based or alternative animal diets (Suresh et al., 2011; Sabry-Neto et al., 2017).

Proteins

Krill meal contains up to 60% of protein with a well-balanced amino acid profile (Nunes et al., 2011) and small, easily digestible peptide sizes. Certain essential amino acids are, however, much more common in krill meal than in fishmeal, which has consequences for growth performance. For example, the amino acids arginine, glutamic acid, histidine and leucine, which are represented in much higher quantities in krill meal than in fishmeal, were directly correlated with specific growth rate and weight gain in grower walleye pollock (*Gadus chalcogrammus*, Choi et al., 2020).

When krill meal compensated the reduction of fishmeal content in the diets of Atlantic salmon (*Salmo salar*), salmon grew equally well, if not faster initially when the diet contained more krill meal (Olsen et al., 2006). Similar results were found for cultured rainbow trout (*Oncorhynchus mykiss*, Wei et al., 2019). The superior amino acid profile in combination with the low molecular weight soluble nucleotides and small peptide sizes might be the underlying reason for this improved performance.

The study by Sabry-Neto et al. (2017) exchanged a fishmeal-based white leg shrimp (*Litopenaeus vannamei*) diet with a plant-based diet, but added krill meal at four levels (0.5, 1, 2, and 3%). Most of the protein in the diets originated from soybean meal, a more sustainable source of protein than fishmeal and the addition of krill meal supplemented essential nutrients and improved feed attractability. Even at a krill meal inclusion as low as 1%, feed conversion rate improved and at 2 and 3% krill meal inclusion, growth performance improved by 16.3 and 20.1%, respectively (Sabry-Neto et al., 2017). A comparable effect was observed in Tilapia (*Oreochromis niloticus*), where exchanging a diet with 20% fishmeal with one based on soybean meal, but with 3% krill meal, increased growth by 28% (Gaber, 2007). This underscores the nutritional benefit arising from krill meal protein for several commercially valuable aquaculture species.

Lipids

Lipids are another group of vital macromolecules. Akin to proteins, lipids play essential roles in metabolic processes such as the storage of energy, signalling information between cells and forming hydrophobic structural components of cell membranes. Lipids come in many forms from fatty acids, triacylglycerol

to phospholipids. But certain essential n-3 PUFAs (polyunsaturated fatty acids), like docosahexaenoic acid (DHA) or eicosapentaenoic acid (EPA), cannot be bio-synthesised *de novo* by many organisms or at least not in sufficient quantities. They must have a dietary source to guarantee performance. Nutritional supplementation with rich sources of these fatty acids is therefore vital.

Krill meal contains around 25% lipids where DHA and EPA make up more than 20% of its fatty acids (Burri et al., 2016). But in contrast to fish oil, where n-3 PUFAs are bound to triacylglycerol, these fatty acids in krill meal are packaged with phospholipids. This, in turn, allows n-3 fatty acids from krill meal to be incorporated into cell membranes more effectively (Rossmeisl et al., 2012). Amplified phospholipid levels supplied from krill, for instance, increased growth and survival in fry of Atlantic salmon (Taylor et al., 2015), the larvae of the large yellow croaker (*Larimichthys crocea*, Feng et al., 2017) and seabream (*Sparus aurata*, Saleh et al., 2013). In the offspring of Atlantic halibut (*Hippoglossus hippoglossus*), the broodstock diet on krill meal improved offspring fatty acid profiles (Mazorra et al., 2003). Besides, the primary phospholipid found in krill meal - phosphatidylcholine - also supplies choline.

Choline is a vital vitamin-like nutrient involved in neurotransmission and osmoregulation. Particularly in aquaculture organisms with both freshwater and marine life stages, like the salmon, where osmoregulation is challenged, choline may support a low-stress transition between these environments.

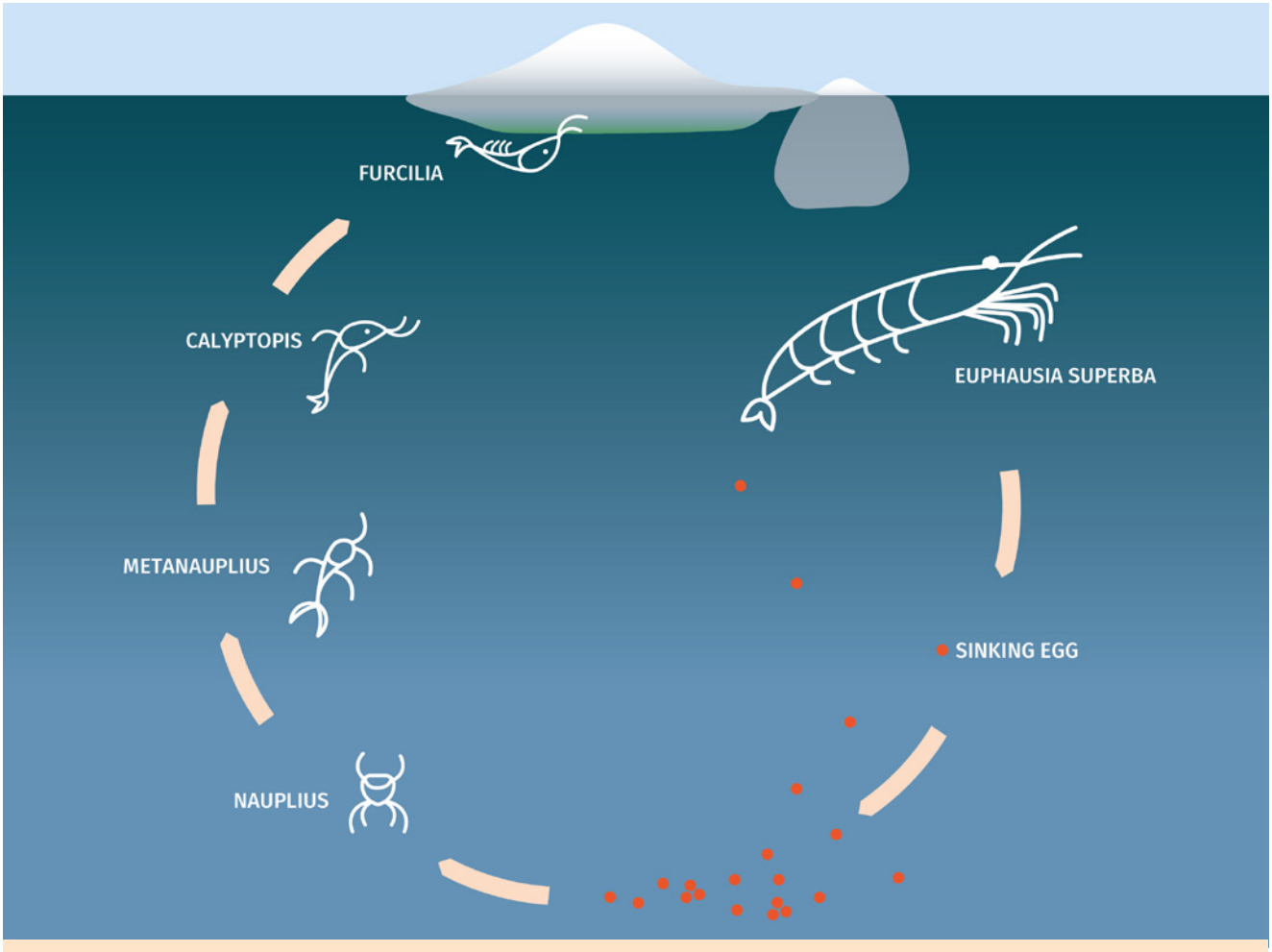
Feed attractants

Phospholipids are also feed attractants, although krill meal additionally contains other feed attractants like chitin, astaxanthin and low molecular weight soluble nucleotides, amino acids and trimethylamine N-oxide (TMAO) (Xie et al., 2019; Wu & Bechtel, 2012; Ali et al., 2007). Such feeding effectors elevate feed attractability and palatability while they reduce feeding latency time, which in turn reduces nutrient leaching and feed wastage. For aquaculture production, this means lower nutrient pollution, fewer costs and less time spent cleaning. For the farmed seafood, feed attractability translates into increased feed intake and, therefore, growth. Furthermore, these feeding effectors enrich krill meal to allow farmed animals to cope with stressful situations such as high density, transfer stress, salinity or temperature changes and diseases.

Feed attractability is, therefore, an important consideration when formulating feeds. In a study that compared the effects of 3% krill meal inclusion on the attractability of a plant-based feed for white shrimp with six marine feed stimulants, feeds containing krill or shrimp head meal were preferred owing to their superior palatability (Nunes et al., 2019). But crucially, final body weight, growth, yield and survival of shrimp fed with shrimp head meal were lower than those fed a krill meal diet. These findings underscore how feed attractability and palatability are key components, but alone will not make up for the poorer nutritional quality of other marine feeds.

Krill – a biochemical power boost

Many feed attractants play a dual role and simultaneously, for example, stimulate the immune systems. Chitin is one such component. The fibrous substance is constructed from polysaccharides and forms a protective outer layer



Krill starts its life underside of sea ice. The ice offers shelter against pelagic predators and food source in form of microscopic algae growing on the ice sheets. As adult, krill become shrimp-like in appearance and migrate to inhabit the open ocean.

of the krill's exoskeleton. In white shrimp, chitin-injected individuals were more immunocompetent and resisted *Vibrio* bacterial infection more easily (Wang & Chen, 2005). Similarly, chitin has been shown to improve the immune system of seabream, particularly the innate cellular immune system, through modulating head-kidney leucocyte activity (Esteban et al., 2000; Cuesta et al., 2003).

Similarly, the antioxidant astaxanthin, a pigment that gives krill, but also salmon or flamingos, its red colouration, has anti-inflammatory properties. In algae, from where the carotenoid pigment originates, it protects its maker from environmental stress. It is therefore unsurprising that the inclusion of astaxanthin krill oil in the diet of *L. vannamei* allowed the shrimp to cope better with osmotic and thermal stress (Nunes et al., 2020).

Krill also contains essential vitamins, such as vitamin A, D and E. Vitamins are macronutrients that like oil in a machine functions to optimise metabolic processes. Stress can cause the denaturation of fatty acids, which as free radicals then disrupt and break other polyunsaturated fatty acids embedded in cellular structures such as the cell wall. This causes tissue damage, which hinders growth, reduces survival and lowers product quality, especially during early development.

Therefore, it is the combination of a rich protein and lipid profile mixed with chitin, astaxanthin, dietary phospholipids, vitamins and other low molecular weight soluble attractants that make krill meal an ideal feed component to improve production and cope with stressful farming conditions while improving animal well-being and farming sustainability.

References are available on request

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