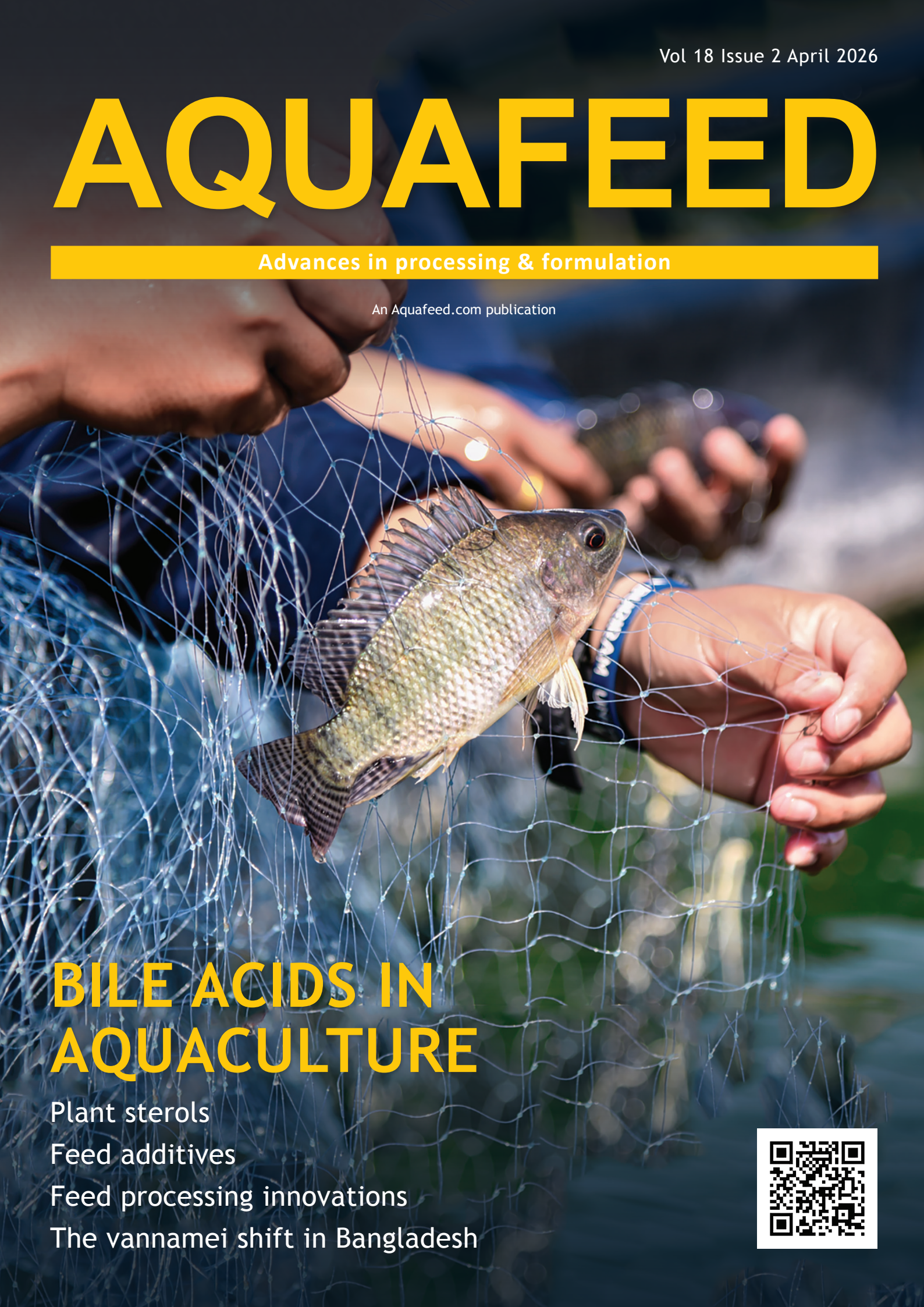
Vol 18 Issue 2 April 2026

# AQUAFEED

Advances in processing & formulation

An Aquafeed.com publication



## BILE ACIDS IN AQUACULTURE

Plant sterols

Feed additives

Feed processing innovations

The vannamei shift in Bangladesh

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**PLANT STEROLS POWER SHRIMP PERFORMANCE 30**
A highly concentrated plant sterols product helps producers improve feed efficiency, manage costs and reduce reliance on marine animal-derived cholesterol.

**HEALTH PROMOTING FEED ADDITIVES 12**
Organic acids and phytobiotics improve shrimp resilience, enhancing feed efficiency, survival, profitability, and environmental sustainability in farming systems.

**HIGH-DENSITY MICROBIAL PROTEIN DELIVERS POSITIVE RESULTS IN SHRIMP 50**
A microbial protein ingredient effectively replaced fishmeal while improving feed efficiency and nutrient utilization in Pacific white shrimp.

**A MULTIFUNCTIONAL WHOLE EGG POWDER 60**
Whole egg powder improves pellet stability, boosting nutrient retention, and supporting better FCR and water quality in shrimp farming.

AQUAFEED

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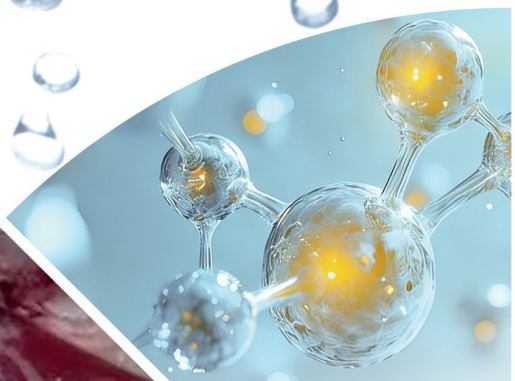
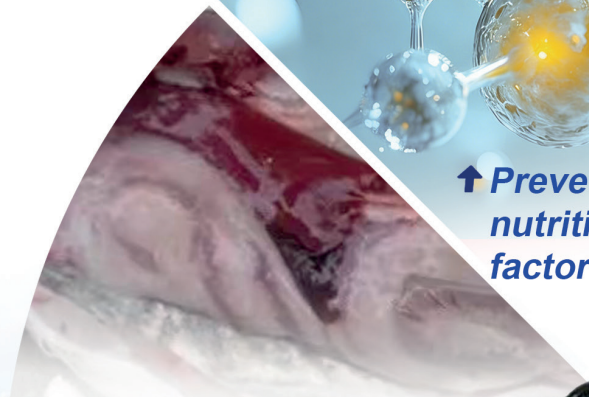
# Tilapia Liver Protector

## RUNEON FEED BILE ACIDS



⬆ Prevent anti-nutritional factors

⬆ Enhance anti-stress ability



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FCR ⬇ 0.03-0.05

Mortality ⬇3-5%

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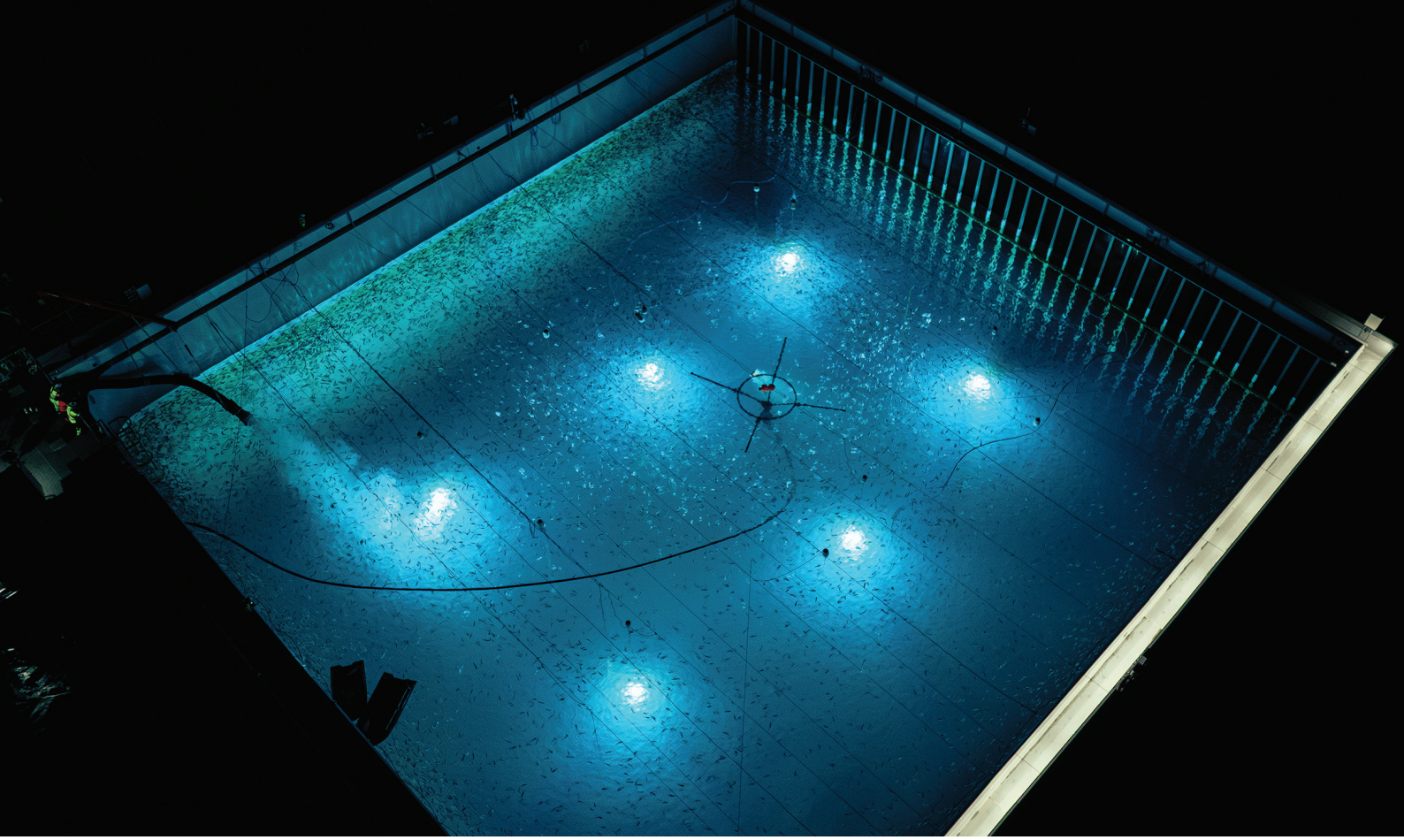


# INTERVIEW *with **Martin Rasmussen** and **Hogne Abrahamsen***

**Martin Rasmussen is CEO of Andfjord Salmon, and Hogne Abrahamsen is CSO - Animal Health at Zooca - The Calanus Company**

**AQ: Andfjord Salmon has developed a unique land-based flow-through farming system. Could you briefly explain the concept behind your production model?**

**MR:** Andfjord Salmon is located at Kvalnes on the island of Andøya, in the Arctic archipelago of Vesterålen in Northern Norway. Our concept is built on an optimal farming location, benefiting from the Gulf Stream's stable sea temperatures, which support better growth during the coldest months and reduce winter disease risks.

Our facility is land-based, featuring large pools designed to replicate the salmon's natural habitat. It operates as a closed flow-through system with laminar water flow, ensuring efficient distribution of fresh seawater while enabling effective waste management. Water is sourced from a depth of 50 meters, protecting fish from external factors such as sea lice. Each pool has a water capacity of 40,000 cubic meters per hour.

After two years of construction, we began production in autumn 2025, stocking 1.1 million smolt across two production units in September and November. So far, operational results have been very strong.

Due to the system's design, built below sea level, we benefit from low energy consumption, around 1 kWh per kilo of produced salmon, which is highly competitive and comparable to closed systems at sea.

**AQ: What are the main operational and biological challenges associated with this new approach?**

**MR:** So far, both operational and biological performance have been very positive. We conduct thorough risk assessments to prepare for potential challenges, as working with biological systems always involves uncertainty.

As this is a new production system, we are continuously gaining experience alongside ongoing construction. Most challenges to date have been related to construction rather than operations.

**AQ: Why did Andfjord Salmon decide to develop feed solutions specifically adapted to this production system?**

**MR:** We wanted a feed specifically designed to match both our technology and our sustainability goals.

Our aim is to differentiate ourselves not only through production methods but also through feed formulation.

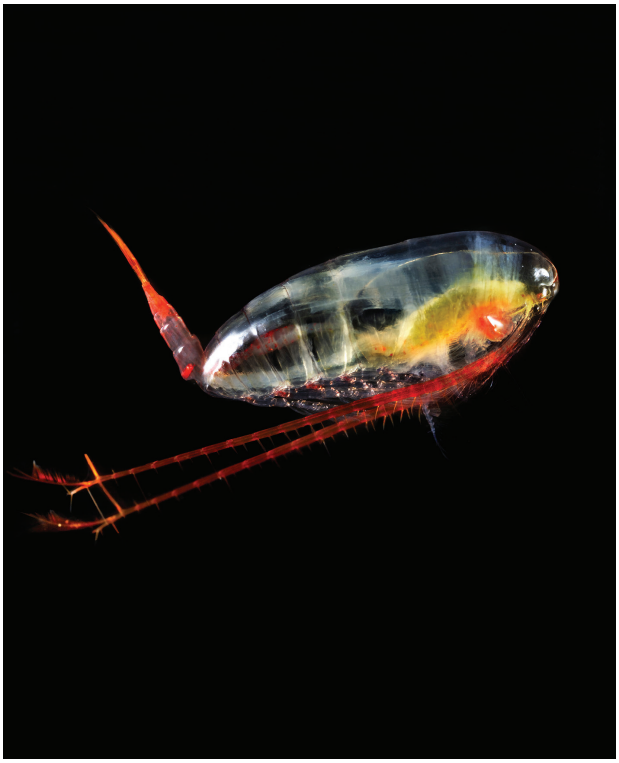
The feed is designed to optimize fish performance, but we also carefully evaluate raw materials and alternative ingredients. This led us to collaborate with Skretting and Zooca.

Zooca is a Norwegian company developing marine ingredients derived from the copepod *Calanus finmarchicus*. It is located close to us geographically, which is important for us as we are especially interested in local and regional resources that can strengthen supply from Norway. More importantly, we share a long-term vision. As the salmon industry grows, it will need to diversify its raw material base. There is still untapped potential in species like *Calanus*.

Moreover, Zooca's hydrolysates appear to have a strong impact on fish welfare and biology. We also see potential benefits from *Calanus* in terms of palatability, which is particularly important during colder months when appetite tends to decrease.

### AQ: Why did Zooca partner with Andfjord?

**HA:** We are a relatively new company with a novel ingredient, and it takes time to scale production and balance price and volume. Initially, we did not target the salmon industry because we could not meet its volume requirements, so we focused on shrimp and marine species.



Now, with established commercial quotas for *Calanus* and a new factory increasing our capacity twelvefold, the timing for collaboration with Andfjord is ideal.

We also share a common vision. Both companies are based in Northern Norway, and we aim to build sustainable value from local resources in a responsible way.

### AQ: How has the feed performed so far?

**MR:** We are seeing very low feed conversion ratios, around 0.87 in one pool and 0.97 in another. Additionally, growth rates are currently about 30% higher than Skretting's standard growth tables.

Scientifically, we cannot attribute this solely to Zooca's ingredient, but we believe it has contributed positively to the overall feed performance.

### AQ: How does Zooca approach ingredient development?

**HA:** *Calanus* is a natural copepod and serves as a "starter feed" in marine ecosystems. Our philosophy is to process it as little as possible and present it in a form that aquafeed producers can use while preserving its natural properties.

We began by testing the product in real-farm conditions, starting with shrimp and seabass. Recent seabass trials have shown improved growth and feed conversion ratios, even when benchmarked against other hydrolysates.

We have also observed increased feed attractiveness in both shrimp and fish. More interestingly, we are seeing metabolic benefits, such as improved oxidative status and enhanced disease resistance, although some of these findings are still pending publication.

Currently, we work with species including shrimp, seabass, trout, and are expanding into wolffish and seriola. Across all species, we consistently observe improved robustness and appetite.

### AQ: What are the next steps for Andfjord?

**MR:** In the first six months since production began in autumn 2025, we have seen very promising results, including survival rates of 97.5%, strong fish welfare indicators, and excellent growth performance.

Our focus moving forward is to increase biomass and production volume while continuing construction of additional production units.

# NEWS REVIEW

Highlights of recent news from Aquafeed.com

## BioMar takes full ownership of BioMar Ecuador, plans capacity expansion

Following a successful partnership that quadrupled company feed volumes from 2019 to 2024, BioMar and the Lanec family have agreed to hand over the full ownership of the company to BioMar. BioMar Ecuador has also decided to expand its production facility capacity from 300,000 to 410,000 tonnes. This will be achieved through debottlenecking and a new line for pelletized feed. This expansion project is expected to be completed in Q3 2026.

## Joint venture to build the world's largest single-cell protein plant in Saudi Arabia


The Saudi Industrial Investment Group, a prominent investor/ operator in the chemical industry in Saudi Arabia, and Unibio International PLC, a biofermentation company, will build the world's largest single-cell protein plant in Saudi Arabia in an 80:20 (SIIG:Unibio) joint venture. The plant will be located in Al Jubail and will produce an initial 50,000 tonnes of Uniprotein® annually, with plans to increase to over 300,000 tonnes in the coming years. The Uniprotein® produced is expected to be sold both domestically and internationally.

## Thai Union Feedmill to invest $55 million in Ecuador's aquaculture business


Thai Union has informed the Stock Exchange of Thailand that Thai Union Feedmill Public Company Limited will invest THB 1,711 million (USD 55 million) to expand its aquaculture business in Ecuador. The Board of Directors approved the company or a newly established subsidiary in Ecuador to invest in the construction of an aquaculture facility in Ecuador. Construction is expected to be completed by 2028. Moreover, Avanti Feeds approved a USD 3 million investment for a 10% stake in Thai Union's subsidiary in Ecuador, strengthening its global partnership to tap into the country's booming shrimp industry.

## dsm-firmenich divests Animal Nutrition & Health to CVC

dsm-firmenich has entered into an agreement with CVC Capital Partners, a global private markets manager, to divest its Animal Nutrition & Health (ANH) business for an enterprise value of about EUR 2.2 billion. ANH will be split into two new standalone companies: the "Solutions Company", including Performance Solutions, Premix, and Precision Services, and the "Essential Products Company", including Vitamins, Carotenoids and Aroma Ingredients (jointly referred to as the "ANH Companies").

## Haid Group opens subsidiary in Singapore

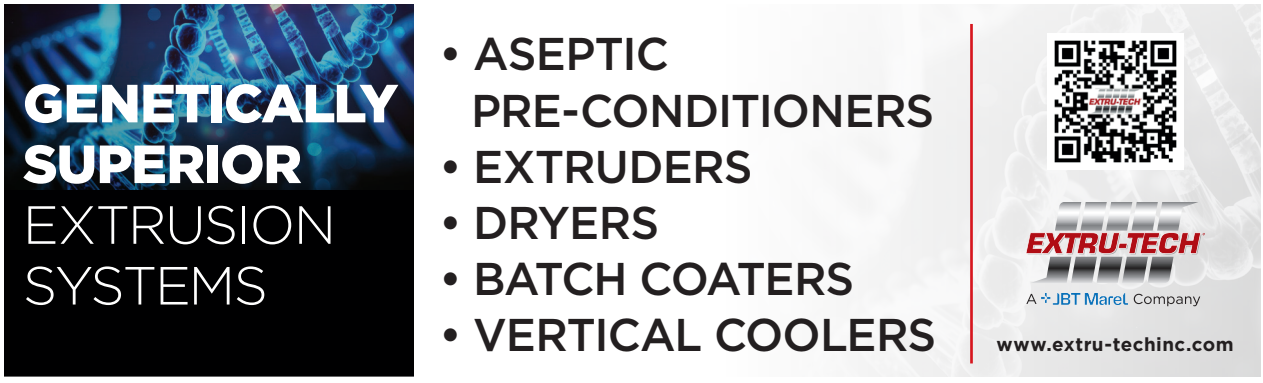
Haid Group opened a new production and R&D facility in Singapore through its subsidiary Haid Singapore, marking a key step in Haid Group's efforts to deepen its global strategic layout. The move is intended to enhance regional food security and support the modernization and sustainable development of Southeast Asia's aquaculture and animal husbandry industries.


## Peru reduces anchovy quota by 36%

Peru has announced that the maximum quota for the first 2026 anchovy fishing season in the North-Central zone will be 1.9 million tonnes. The quota is 36% lower than the 3 million tonnes set in 2025, which was the highest since 2018.

## Blue Fish Factory unlocks new value from marine by-products

Blue Fish Factory is launching its first hydrolysate powder, Hydromax. The product is produced exclusively from canning industry by-products of wild-caught pelagic fish, primarily sardines. Hydromax delivers EPA + DHA at around 30% of total fatty acids, with a meaningful phospholipid content that enhances the bioavailability of the finished product. More than 90% of its peptides are below 5 kDa, which, combined with a pepsin digestibility of 95%, makes the product effectively hypoallergenic. The company's current facility is designed for a production capacity of 2,000 to 3,000 metric tons of finished product per year at steady state, split approximately 80% hydrolysate powder and 20% fish oil.



## Royal Agrifirm Group acquires Hamlet Protein

Royal Agrifirm Group has reached an agreement to acquire Hamlet Protein, a specialty soy-based protein ingredients supplier for young animal nutrition. Hamlet Protein will continue operating under its own name as part of Royal Agrifirm Group. Both organizations will work closely together to combine their capabilities and further strengthen differentiated nutritional concepts for their valued customers in the global feed industry.


## BioMar to expand aquafeed production in China

BioMar has announced plans to expand its Wuxi production facility in China, adding a second line in 2026. The expansion aims to double capacity while allowing the facility to produce feed for a broader range of species at primary growth stages. Currently, the Wuxi facility produces feed for species including trout, salmon, sturgeon, largemouth bass, turbot, and yellow croaker.
The new line will also allow production of advanced nursery feed and feed for emerging species, including Japanese eel, grouper, and mandarin fish.

## Aller Aqua launches new concept to enhance aquafeed performance through trace elements

The company has released its Trace Elements Adjusted (TEA) concept, a formulation update that incorporates a significantly broader range of essential trace elements than ever before. Aller Aqua aims to provide a more sustainable approach to improving stock health and farm performance.

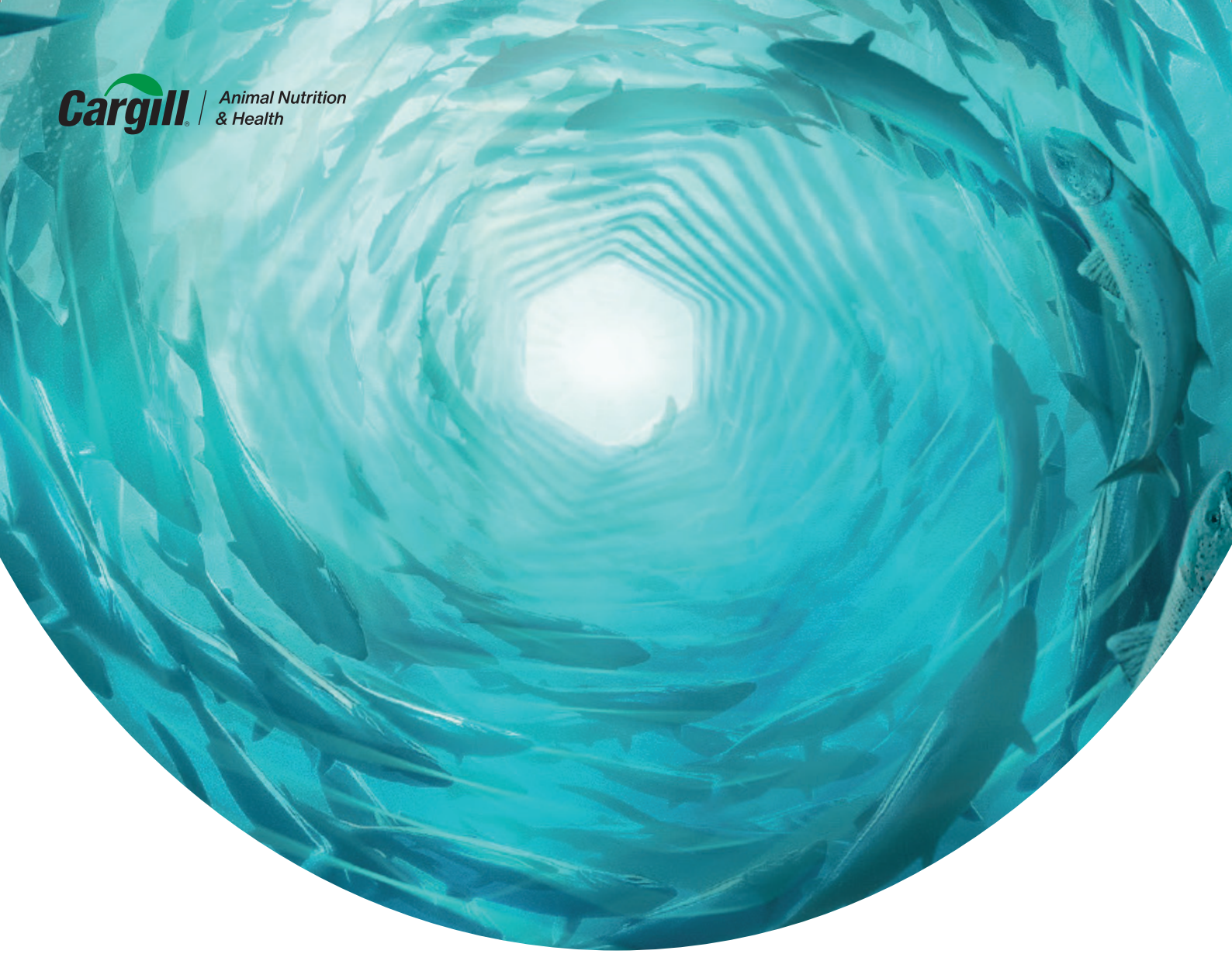

## Aquasorgal becomes the new identity of Aquasoja

Aquasoja has rebranded to Aquasorgal as part of a strategy to accelerate international growth and strengthen its presence in new markets. Aquasorgal continues to expand its international footprint, supplying nutritional solutions to aquaculture producers across global markets.

AQUASORGAL

## Aquaculture nutrition expert Johan Schrama passes away

Johan Schrama has passed away, leaving behind a significant legacy in aquaculture nutrition science. As Professor in the Aquaculture and Fisheries (AFI) group at Wageningen University & Research, he made lasting contributions that helped shape the field.




# Next Level. Realized.

## Rethinking Aquaculture Performance with Integrated Solutions

Aquaculture operations are becoming more complex, harder to control and harder to predict.

Cargill Animal Nutrition & Health (ANH) integrates science-backed micronutrition, aquaculture expertise, and digital platforms into one system—built for real-world farming conditions.

By connecting what happens in the water to decisions on the farm, this approach helps improve efficiency, resilience, and decision-making—delivering more predictable, measurable aquaculture performance.

**Discover More**

# Health-promoting feed additives to enhance resilience, profitability and environmental efficiency in shrimp farming

**I-Tung Chen, Alex Makol, Maria Mercè Isern-Subich, Waldo G. Nuez-Ortín**
Adisseo SAS

In shrimp farming, profitability depends on small margins. A slight increase in feed conversion ratio, a small drop in survival, or uneven growth sizes can determine whether a production cycle makes a profit or loss. Behind these variations, shrimp health plays the central role. FCR is one of the most sensitive indicators of this health. Because feed represents the largest production cost, even small changes in feed efficiency directly affect profitability. Supporting health, therefore, means protecting economic performance.

## Environmental stress and its impact on performance stability

Shrimp are cultured in open systems that are increasingly affected by environmental instability. Water temperatures are rising, dissolved oxygen levels fluctuate, and heavy rainfall can suddenly alter salinity or pH. These conditions create continuous physiological stress. When shrimp are physiologically stable, nutrients are converted efficiently into biomass. Under stress, however, shrimp must allocate more

metabolic energy to maintain internal balance, leaving less energy available for growth and immune defense. Environmental stress can also disturb gut microbiota and allow opportunistic bacteria to proliferate. Warmer water further accelerates the multiplication of Vibrio species. When environmental stress, weakened host defense, and pathogen pressure occur simultaneously, the risk of disease outbreaks increases. Growth slows and FCR increases, often before visible clinical signs appear. These hidden losses accumulate over time and reduce overall performance.

## Building resilience to maintain growth and feed efficiency

In this situation, building animal resilience becomes essential. Resilience includes disease resistance as well as the ability of shrimp to tolerate stress, maintain stability, and recover efficiently after challenges. In commercial production, pathogen exposure is part of normal farm reality, and the key factor is how shrimp respond to it. The economic outcome depends on how quickly shrimp restore feed intake, growth rate, and feed efficiency after disturbance. Fast recovery limits losses, while asymptomatic or slow recovery leads to size variation, poor feed utilization, and prolonged instability.

In practical farming conditions, health is reflected in performance consistency. Functional feed additives for health are increasingly implemented to support robustness and reduce stress and disease pressure. Health additives such as organic acids and phytobiotics are characterized by synergistic compositions and multiple modes of action. Organic acids provide selective bacterial growth inhibition activity in the digestive tract. By limiting harmful bacteria while maintaining beneficial populations, they improve gut conditions and support feed efficiency under pathogen pressure. Phytobiotic-based additive, derived from plant bioactive compounds rich in phenolics and essential oils, provides broader spectrum protection. In addition to microbial control effects, they offer antioxidant protection, support immunocompetence, and improve gut integrity. The synergistic activity helps shrimp maintain stable survival, regular feed intake, efficient nutrient use, and predictable growth throughout the cycle (Caipang *et al*., 2020).

## Preventive and corrective health strategies in shrimp farming

Health management strategy by functional additives can follow either a corrective or a preventive approach. Corrective strategies begin after disease signs are observed, when pathogen levels are already high, and shrimp are weakened. Costs include mortality and treatment expenses, while hidden losses arise from reduced growth and poorer feed efficiency. Preventive strategies are applied before predictable stress periods or from the start of the production cycle, building resilience before major challenges occur. Although preventive supplementation requires an initial investment, it helps shrimp maintain physiological balance under pressure and reduces long-term variability. Resilient shrimp return to normal growth more quickly after a challenge, stabilizing production outcomes.

Adisseo's aqua health portfolio combines organic acid and phytobiotic-based solutions that help shrimp build robustness, reduce infection severity, and better cope with production challenges. The biological benefits enhance disease prevention and overall resilience, which in turn translate directly into economic performance.

Field studies conducted in farms affected by white feces syndrome (WFS) and EHP compared corrective and preventive strategies. Corrective supplementation improved survival and feed efficiency compared to untreated ponds, while the combination of preventive and corrective approaches delivered the most consistent results, increasing survival from around 35% in affected ponds to approximately 66% or higher, while reducing FCR by 25 to 33 %. More importantly, under combined strategies, growth performance recovered to levels comparable to those observed before major disease outbreaks. Across countries and multiple production cycles, this restoration of performance translated into measurable improvements in biomass yield and return on investment under commercial conditions (Chen *et al*., 2023).

## Improving production efficiency to reduce carbon footprint

Improved biological efficiency through the supplementation of health additives also has environmental implications. Life Cycle Assessment (LCA) studies conducted at farm level have demonstrated that better survival and feed efficiency significantly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reduce greenhouse gas emissions. Under high disease pressure, the benefits of preventive and corrective supplementation reduced baseline emissions from approximately 6.2 kg $CO_2$ equivalent per kg of shrimp to 3.7 kg $CO_2$ equivalent per kg of shrimp, representing an overall reduction of about 38%.

Because feed production is one of the main contributors to the carbon footprint of shrimp farming, improving feed conversion efficiency reduces the total amount of feed required. This lowers emissions associated with feed manufacturing, transportation, and nutrient related gases. Additionally, better survival rates and higher biomass yields further cut emissions per unit of production by reducing on farm energy use.

## Animal resilience as a foundation for sustainable shrimp farming

Building animal resilience is essential in shrimp farming. As environmental conditions become increasingly variable, maintaining biological stability is key to sustaining performance. Prevention through health functional feed additives provides a practical approach to enhance resilience and animal homeostasis. This approach not only strengthens long term profitability but also contributes to more environmentally friendly farming practices.

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# THE HIDDEN SIDE OF HEALTH: PERFORMANCE

In aquaculture, there is a hidden part of health that guarantees more predictable performance and greater profitability: the strength of natural defences, the ability to respond to stress, and function of healthy tissues.
Adisseo delivers species-specific solutions to boost the resilience of fish and shrimp, enabling farmers to optimize health management.

## Turn resilience into predictable performance!

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# A review of the application of bile acids in aquaculture

**Dr. Wei Zhang**
Lachance Synthetic Biotechnology Co., Ltd.

Bile acids are the primary active components of animal bile, synthesized in the liver and stored in the gallbladder. As efficient, green, non-nutritive feed additives, bile acids have been extensively studied and applied in aquaculture. Their functions extend beyond promoting fat utilization, providing comprehensive benefits for maintaining liver and intestinal health, and enhancing immunity and stress resistance in aquatic animals.

## Core mechanisms of action

The effects of bile acids in aquatic animals are multifaceted, with core mechanisms summarized as follows:

- *Promoting lipid metabolism:* As natural biosurfactants, bile acids effectively reduce the surface tension of dietary lipids, emulsifying them into micelles. This significantly enhances lipase activity, thereby facilitating the digestion, absorption, and transport of fats.
- *Maintaining liver health:* Bile acids promote the secretion of dilute bile from the liver, clearing biliary ducts. This alleviates the liver's burden caused by nutritional excess or toxin accumulation, aids in repairing damaged hepatocytes, and demonstrates significant efficacy in preventing conditions such as fatty liver and liver syndrome.

- *Enhancing intestinal barrier function:* Bile acids can bind to or decompose intestinal endotoxins (e.g., bacterial lipopolysaccharides), inhibit the excessive proliferation of harmful bacteria, while simultaneously promoting the growth of beneficial bacteria. This optimizes the structure of the intestinal microbiota, thereby maintaining the integrity of the intestinal mucosa and improving intestinal health.
- *Improving stress resistance:* Research indicates that bile acids can increase the activity of non-specific immune factors in the serum of aquatic animals, such as glutathione peroxidase and superoxide dismutase (SOD). This enhances the body's antioxidant capacity and disease resistance.

## Application effects and recommended dosages in different aquatic animals

Numerous studies have confirmed that the scientific addition of bile acids to feed positively impacts the growth performance, feed utilization, and health status of various aquatic animals. Representative application data for selected species are as follows:

***Shrimp*** (*Litopenaeus vannamei*)

The application of bile acids is particularly crucial in shrimp farming. Studies show that adding bile acids to feed effectively improves hepatopancreas health and enhances the shrimp's ability to cope with environmental stress and disease. Research indicates that adding 200 mg/kg of bile acids (purity >98%, same below) significantly increases final body weight by 8.53%, weight gain rate by 9.67%, specific growth rate by 4.05%, and reduction in feed conversion ratio (FCR).

***Grass carp*** (*Ctenopharyngodon idella*)

Research on grass carp has found significant benefits when bile acids are added to low-protein diets. At an inclusion level of 60 mg/kg, the weight gain rate of grass carp increased by 10.38%, accompanied by significant improvements in muscle quality and disease resistance. This offers a viable solution for reducing dietary protein levels while maintaining profitability.

***Tilapia*** (GIFT *Oreochromis niloticus*)

Adding bile acids to tilapia feed effectively promotes the utilization of plant-based protein sources. Multiple studies indicate that adding 150 mg/kg of bile acids significantly improves final body weight, weight gain rate, specific growth rate, and protein efficiency ratio in GIFT tilapia, while reducing FCR. Research by Professor Shao Qingjun's team further established the precise supplemental level of bile acids in tilapia feed at 0.15 g/kg (150 mg/kg), achieving optimal weight gain and feed efficiency at this level.

Table 1. Recommended dosage and key effects of bile acids in selected aquaculture species.

| Species | Recommended dosage (mg/kg feed) | Key effects and verified results |
|---|---|---|
| Grass carp | 60 | Promotes growth, improves flesh quality, enhances antioxidant capacity: Supplementation at 60 mg/kg significantly increases weight gain rate, specific growth rate, reduces FCR; effectively reduces muscle fat deposition, increases protein content; elevates activity of antioxidant enzymes (SOD, GSH-Px) in serum and liver. |
| Tilapia | 150 | Improves feed efficiency, protects liver: Supplementation at 150 mg/kg significantly increases final body weight, weight gain rate, and protein efficiency ratio, while reducing FCR and hepatosomatic index (HSI). In low fishmeal or plant-based protein diets, it effectively improves lipid metabolism and reduces hepatic fat deposition. |
| Shrimp | 200 | Protects hepatopancreas; synergistic cholesterol replacement: Supplementation at 200 mg/kg significantly improves hepatopancreatic health, restoring hepatopancreatic tubule structure. In low-fishmeal diets, when combined with cholesterol, it effectively replaces a portion of dietary cholesterol, mitigating growth reduction and metabolic imbalance caused by reduced fishmeal inclusion, improving weight gain rate and reducing FCR. |
| Largemouth bass | 300 | Alleviates stress from high-fat diets, improves liver health: In high-fat diets, supplementation at 300 mg/kg significantly mitigates the decline in liver antioxidant capacity and oxidative damage induced by high-fat intake, improves hepatocyte morphology, and reduces fat accumulation. Studies show that 300 mg/kg significantly improves weight gain rate and specific growth rate. |

***Seabass/largemouth bass*** (*Micropterus salmoides*)

As high-value carnivorous fish, bass are often fed high-protein, high-fat diets to promote rapid growth, which can easily lead to increased metabolic burden on the liver, resulting in fatty liver and hepatobiliary dysfunction. Bile acid supplementation offers a targeted solution for such issues.

***Regulatory effect on high-fat diets***

Studies show that feeding largemouth bass high-fat diets significantly reduces liver antioxidant capacity (e.g., SOD activity) and induces oxidative damage. Supplementing the feed with 300 mg/kg of bile acids effectively reverses this condition, significantly enhancing the liver's antioxidant status and protecting hepatocyte structure. It also significantly increases the rate of weight gain and specific growth rate in largemouth bass while reducing hepatic fat deposition and optimizing lipid metabolism.

***Maintaining liver and intestinal health for optimal performance***

In seabass aquaculture, liver and intestinal health are crucial determinants of survival rate and feed conversion efficiency. Through its dual actions of protecting the liver/gallbladder and regulating the intestine, bile acids effectively prevent hepatobiliary syndrome, reduce issues like weakness and decreased disease resistance caused by metabolic disorders, thereby stabilizing growth performance and reducing morbidity during the mid-to-late culture stages.

## Application strategies

***Precise supplementation***

The optimal inclusion level of bile acids should be finely adjusted based on factors such as the cultured species, growth stage, and the basal diet composition (especially fat and protein levels).

***Synergistic effects***

Bile acids exhibit clear synergistic effects with nutrients like cholesterol and phospholipids in the diets of shrimp and crabs. Combined use can more efficiently promote growth and maintain health. In low-fishmeal, high-plant-protein formulations, adding bile acids can significantly improve fat and fat-soluble vitamin absorption, compensating for nutritional deficiencies arising from ingredient changes.

***Holistic health management***

Beyond being used as a growth promoter during rapid growth phases, bile acids should be applied regularly as a health management agent for liver protection, detoxification, and immune enhancement during critical periods such as the "liver transformation" phase, high-temperature seasons, periods of high disease risk, or before/after drug administration. This approach embodies the health management philosophy of "protecting the liver and intestine through integrated prevention and control."

## Conclusion

In summary, bile acids are a green feed additive with well-defined mechanisms and comprehensive efficacy. Acting from the source of digestion and absorption, they systematically enhance the production performance and health status of aquatic animals through multiple pathways, including regulating lipid metabolism, maintaining liver and intestinal health, and boosting immunity. As aquaculture continues to evolve towards intensification, reduced reliance on fishmeal, and ecological sustainability, the metabolic stress faced by farmed animals is increasing. As a functional additive that effectively addresses these challenges, bile acids hold promising applications. Future research directions will focus on deeper mechanistic studies and the development of precise application protocols tailored to different aquaculture models, which will be key priorities for the industry and technical services.

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# Rethinking vitamin D bioavailability in aquafeeds

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dsm-firmenich Animal Nutrition & Health

For over a decade, farmed fish have surpassed wild-caught fish for human consumption, and it is predicted that aquaculture will supply 60% of the world's fish and shrimp by 2030 (FAO, 2014). As aquaculture continues to scale globally, the industry is under increasing pressure to optimize fish health, performance, and product quality while transitioning to more sustainable, plant-based feed systems. In this context, micronutrients such as vitamin D are coming under renewed scrutiny in terms of inclusion levels and how effectively they are absorbed and utilized. Understanding bioavailability from modern feed formulations is key to the advancement of aquafeeds, and consequently, an area where dsm-firmenich Animal Nutrition & Health and other innovators are helping to advance more effective nutritional solutions. This shift is driving a re-evaluation of traditional approaches and opening the door to more science-driven strategies.

Accounting for how the environments of farmed fish differ from nature and what effects this has on vitamin absorption and utilization is critical. In natural settings, fish obtain vitamin D through both their diet

and dermal synthesis stimulated by sunlight. Modern environments such as indoor tanks, recirculating aquaculture systems (RAS), submerged sea cages, and other closed containment technologies have become more widespread. Moreover, questions arise over vitamin D adequacy in fish raised over the winter months. These environments often limit fish's exposure to natural sources of vitamin D, such as sunlight, further compounding the challenge. For example, vitamin D has been suggested as a possible cause of persistent winter wounds. However, the inclusion of cholecalciferol (D3) alone is not enough, as vitamin D must be converted into its active form before it can perform its biological functions. This awareness has led to a shift in prioritizing its bioavailability in feed formulation.

The need for a readily available form of vitamin D led to a shift, as reflected in the recent EU authorization of Hy-D® (25-OH-$D_3$), a new form of vitamin D that bypasses initial metabolic conversion. Its use has been associated with improvements in performance, nutrient retention, wound recovery, carcass yield, and overall product quality. This only further highlights the broader evolution and approach to vitamin D nutrition in aquaculture.

## Vitamin $D_3$ in aquaculture diets over time

From the early 2000s to the late 2010s, vitamin $D_3$ levels in salmonid diets declined significantly, falling from approximately 400-500 µg/kg in 2003 to just 10-30 µg/kg by 2018-2019 (adapted from Sissener *et al.*, 2013). This is a reduction of more than 90% over approximately 15 years. This trend largely reflects the industry-wide transition away from fishmeal and fish oil toward plant-based ingredients, which contain little to no natural vitamin $D_3$.

Despite being required in relatively small amounts, vitamin $D_3$ plays a disproportionately large biological role. It is the only physiologically relevant form of vitamin D for fish, and when activated by the fish, it functions more like a regulatory hormone than a simple nutrient. By influencing the expression of an estimated 2-5% of the genome, it helps control essential processes including immune response, ion balance, skeletal development, nutrient metabolism, and growth.

The scale of this nutritional shift has had significant biological consequences. In response, EU regulations were updated in May 2019 to increase the maximum permitted level of cholecalciferol (vitamin $D_3$) in salmonid feeds, although this adjustment was limited to salmonids due to insufficient safety data for other species. While this change addressed dietary inclusion levels, it did not fully resolve the underlying challenge.

## The EU approval of Hy-D® and its significance

In December 2025, the European Food Safety Authority confirmed the safety and efficacy of Hy-D® and the European Commission subsequently authorized its use in aquaculture. This is the first approval of 25-hydroxycholecalciferol for salmonids and all other aquatic species and represents an important milestone for the aquaculture industry. Obtaining approval for novel feed technologies is not straightforward; this approval reflects a 25-year effort to make the benefits of Hy-D® available across the European Union. It also advances the company's mission to provide safe, effective, and sustainable nutritional solutions.

Research trials show the advantages of Hy-D® over traditional $D_3$ supplementation. As widely reported, in fish raised indoors, trout fed standard recommended levels of $D_3$ for 84 days had plasma 25-OH-$D_3$ levels that remained barely detectable. In contrast, Hy-D® overcame limits in the fish's utilization of D3 activation, ensuring hormonal sufficiency and physiological benefits (adapted from Rider *et al.*, 2023). This demonstrates the superior bioavailability of Hy-D® and its ability to support growth, immune function, and overall fish health, making it a valuable tool in modern aquaculture nutrition.

## Impact of low vitamin D and the benefits of Hy-D®

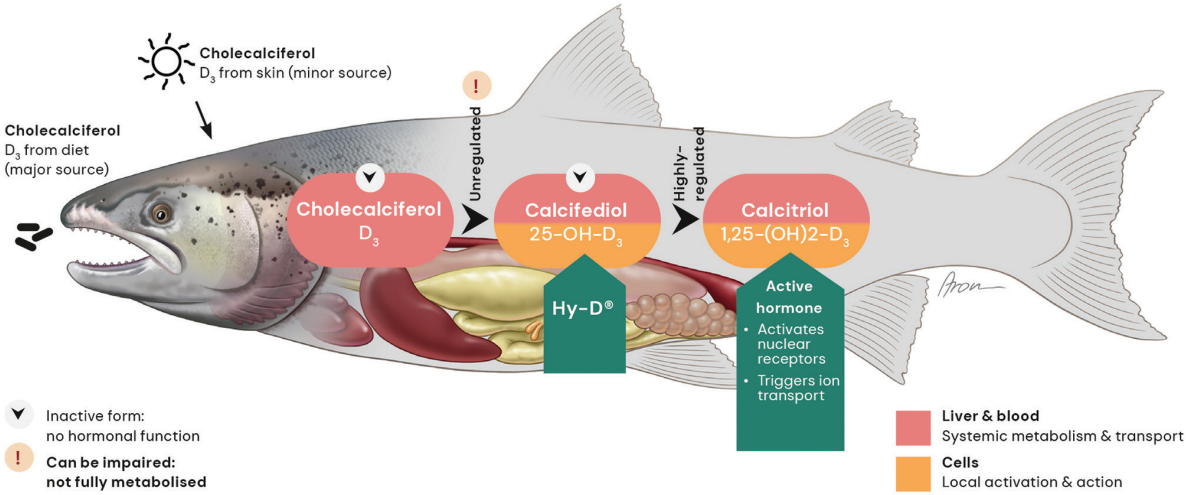
Low vitamin D status can lead to thinner skin, reduced robustness and a higher risk of injury, particularly during winter or mechanical handling events such as well-boat treatments.

It can also weaken immune function, increasing susceptibility to secondary infections. However, trials in trout comparing standard vitamin packages with OVN™ plus Hy-D® showed reduced wound expansion, demonstrating improved tissue repair and thus improved product quality and resilience (adapted from Rider *et al.*, 2023).

Hy-D® also positively influences lipid metabolism and feed-to-carcass conversion efficiency. In Atlantic salmon fed for 90 days, increasing dietary 25-OH-$D_3$ reduced mesenteric adiposity, while increasing carcass yield by approximately 1% compared to diets

## How fish activate vitamin D

Vitamin D needs to be metabolised to become active in fish




without Hy-D®. Field observations in Chile also indicate reductions in bone deformities and fillet gaping. By supporting connective tissue and muscle structure, Hy-D® contributes to better fillet texture and product consistency (adapted from Rider *et al.*, 2024).

Cholecalciferol, or vitamin $D_3$, is biologically inactive and must first be converted in the liver to 25-hydroxyvitamin $D_3$ before being activated at the tissue level. In fish, both hydroxylation steps occur in the liver, which makes liver health critical for effective vitamin D metabolism. Delivering vitamin D in a form that fish can effectively use is critical. Hy-D® provides a science-based solution to long-standing metabolic limitations, improving growth, feed efficiency, welfare, product quality and consumer value while remaining within regulatory frameworks. Optimizing vitamin D nutrition addresses a key bottleneck in modern aquaculture.

### The future of precision nutrition

Feeding a growing global population sustainably will require continued scientific innovation to balance high-quality protein production with environmental responsibility. dsm-firmenich Animal Nutrition & Health is actively addressing this need through ongoing research and trials designed to better understand the role of vitamin D in protecting against both viral and bacterial diseases.

Future investigations will be important not only for fine-tuning optimal inclusion levels but also for exploring how vitamin D interacts with other essential micronutrients and contributes to the overall metabolic and immune status of fish.

By advancing knowledge of how vitamin D can be delivered in a highly bioavailable form, the aquaculture industry can achieve measurable improvements in growth performance, product quality and animal welfare while staying within regulatory frameworks. Precision micronutrition, including the use of Hy-D®, is therefore a key component of sustainable aquaculture.

As vitamin D levels in fish feeds and fillets decline due to the shift towards plant-based ingredients, the need for more efficient solutions is increasingly important. The focus needs to shift from measuring feed $D_3$ to measuring blood 25-hydroxy levels, as it is measured in humans. The reason is that $D_3$ metabolism is limited. In humans, vitamin D status is not measured by $D_3$ intake, but by blood 25-hydroxy levels. We see that it should be the same in fish, and the question becomes, do our fish have enough 25-hydroxy in their blood?

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# A yeast-based natural attractant sparks stronger appetite in tilapia

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[1]Maverick Innovation, [2]PSIS Link Co.

Maverik Innovation aquaculture facilities.

Feeding behavior is a key determinant of growth performance and feed efficiency in aquaculture, and the use of feed attractants has become an important strategy to enhance voluntary feed intake under intensive production conditions.

Feed attractants stimulate feeding via chemosensory pathways, thereby enhancing palatability and feed detection, particularly when environmental or management factors suppress appetite (Kasumyan & Døving, 2003). Among available attractants, yeast-based products have gained prominence due to their high concentrations of free amino acids, peptides, nucleotides, and volatile compounds that act as potent feeding stimulants in many teleost species (Glencross *et al*., 2015; Li *et al*., 2009).

Yeast metabolites not only enhance sensory cues but also provide functional nutrients that may support gut health and immune function (Hernández *et al*., 2010; Ringø *et al*., 2020). Previous studies have demonstrated improved feed intake and growth in species such as tilapia, carp, and marine carnivores when yeast derived attractants are included in diets, although optimal inclusion levels vary widely (Lara Flores, 2011; Luo *et al*., 2012). Despite their increasing use, controlled dose-response studies that account for daily environmental variation remain limited.

The present study evaluated the effect of graded levels of a yeast metabolite-based attractant on feed intake in Nile tilapia (*Oreochromis niloticus*) over a 15-day period. Dissolved oxygen (DO), temperature (Temp), and day to day variation were incorporated into the analysis to better understand how attractant level interacts with environmental factors.

The objective was to determine whether the attractant level significantly influences feed intake and identify the optimum inclusion level under the tested conditions.

## Materials and methods

The attractant was designed by Maverick Innovation (Bangladesh) comprised of yeast metabolites, functional amino acids and minerals, and manufactured by Topnutriyeast Biotechnology, Tangshan, Hebei, China.

### *Experimental design*

A 15-day feeding trial was conducted at the RAS facility of Maverick Innovation using five experimental diets containing graded levels of the attractant (0.0, 0.5, 1.0, 1.5, and 2.0%). The attractant was mixed thoroughly with the basal feed immediately before the trial to ensure uniform coating and preserve volatile attractant compounds.

### *Fish and rearing conditions*

A total of 1,000 juvenile Nile tilapia (mean body weight ≈ 15 g) were equalized by weight two days prior to the trial to minimize size related variation in feeding behavior. Fish were then randomly distributed into five 1,100-L tanks, with 200 fish per tank. All tanks were continuously aerated, and water quality parameters were monitored daily.

### *Feeding protocol*

A rotational feeding schedule was used to ensure that each tank received each of the five diets exactly three times over the 15-day period. This rotation minimized tank effects and allowed each tank to serve as its own control across diets. Feeding occurred once daily at 09:00 AM.

### *Measurement of feed intake*

Fish were fed slowly until they stopped feeding, following a standardized apparent satiation protocol. Feed was offered in small portions, and additional feed was provided only while fish remained active. Once feeding activity ceased, no further feed was added.

Daily measurements of dissolved oxygen (DO) and temperature (Temp) were recorded concurrently to account for environmental variation.

### *Statistical analysis*

Feed intake was analyzed using a randomized complete block design (RCBD), with Day as the blocking factor and Level as the fixed treatment. DO and Temp were included as covariates. A quadratic regression model was fitted to estimate the optimum attractant inclusion level. All analyses were performed using ExcelStat.

## Results

### *Effect of the attractant level on feed intake*

Attractant Level had a significant effect on feed intake after controlling for Day, DO, and Temp ($p$<0.05). All four treatments showed significantly higher feed intake compared to the control. There were no statistically significant differences in feed intake among 0.5, 1.0 and 1.5 kg/MT dosages, whereas feed intake in 2.0 kg/MT dosage treatment was significantly higher than 0.5 and 1.0 kg/MT treatments (Figure 1).

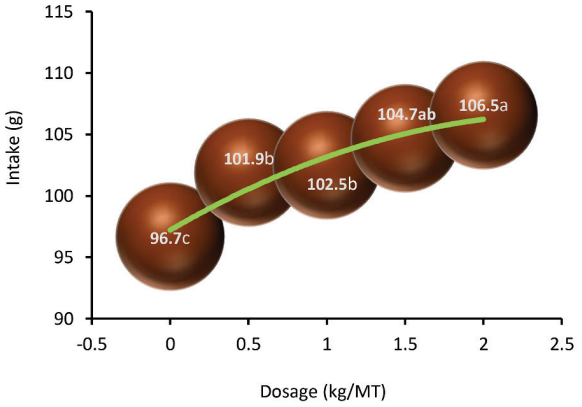


Figure 1. Average feed intake by Nile tilapia juveniles fed diets containing 0, 0.5, 1.0, 1.5 and 2.0 kg/MT of the attractant. Different letters indicate significant differences at $p$<0.05.

### *Effect of DO and temperature*

Higher DO was associated with increased feeding activity, while temperature exerted a smaller but detectable effect consistent with known thermal influences on tilapia feeding behavior.

### *Block (day) effect*

Day was a significant blocking factor ($p$<0.001), confirming substantial day-to-day variability in feeding response and validating the use of an RCBD (Figure 2).

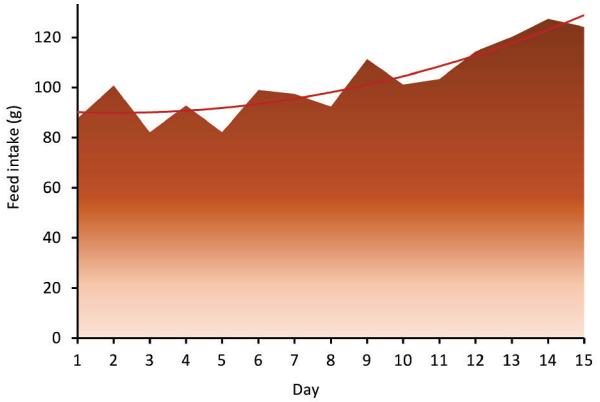


Figure 2. Combined average daily feed intake by Nile tilapia juveniles fed diets containing 0, 0.5, 1.0, 1.5 and 2.0 kg/MT of the attractant.

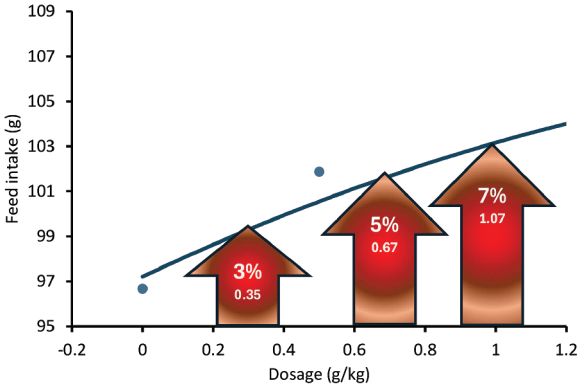


Figure 3. Calculated dosages of the attractant to increase feed intake by 3%, 5% and 7% by Nile tilapia juveniles.

***Quadratic model and optimum level***

The quadratic regression model revealed a significant curvature effect of Level on intake. The estimated inclusion level 0.346, 0.673, and 1.069 kg/MT of feed for 3, 5, and 7% increase in feed intake, respectively (Figure 3).

## Discussion

The results demonstrate that the attractant significantly enhanced feed intake in Nile tilapia. The pattern aligns with classical dose-response relationships in aquaculture nutrition, where moderate supplementation enhances palatability and feeding stimulation, but excessive levels yield diminishing marginal benefits (De Silva & Anderson, 1995; NRC, 2011).

The significant effects of DO and Temp highlight the importance of environmental covariates in feeding behavior. Elevated DO supports aerobic metabolism and feeding activity, a relationship well documented in warm water species such as tilapia (Boyd *et al.*, 2018). Temperature effects were modest but expected, as feeding rate is tightly linked to thermal conditions within the species' optimal range (Azaza *et al.*, 2010).

The strong Day effect underscores the biological variability inherent in daily feeding patterns. Incorporating Day as a blocking factor improved model precision and prevented confounding, consistent with recommendations for RCBD designs in aquaculture trials (Gjedrem & Baranski, 2009).

The quadratic model provided a biologically meaningful and cost-effective inclusion level of between 0.3-1.1 kg/MT. This suggests that inclusion beyond this range may be economically inefficient. Similar plateaus have been reported in studies evaluating yeast derived attractants and functional feed additives (Luo *et al.*, 2012; Ringø *et al.*, 2020).

Overall, the findings support the use of the attractant at a dosage between 0.35-0.67 kg/MT for a 3-5% increase in feed intake.

*References available on request.*

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# Soy protein concentrate: A value-added soy product for aquafeeds

**Andreas Brezas**
CJ BIO

As aquaculture grows, the industry needs reliable and nutritionally effective alternatives to fishmeal. Soy protein concentrate (SPC) is a value-added soy product with higher protein content and substantially reduced antinutritional factors compared with soybean meal and other plant proteins. These characteristics make SPC a promising option for aquafeeds, with studies showing good performance, digestibility, and adequate nutrient utilization.

## Background

Aquaculture is the world's fastest-growing industry in the food production sector. It is projected that aquaculture will play a major role in the global food supply, with production doubling and intensifying by 2050 (Glencross *et al.*, 2020). It is well known that the sustainability of aquaculture production relies heavily on the availability and use of viable compound feeds and raw materials. In 2022, global aquaculture production reached a new record of 130.9 million

metric tonnes, including 94.4 million tonnes of aquatic animals, while the global aquaculture feed production in 2024 was estimated at almost 53 million metric tonnes (FAO 2024; Alltech 2025). Looking ahead, world aquatic animal production is projected to reach 205 million metric tonnes by 2032, with aquaculture expected to contribute 111 million metric tonnes, confirming the continued strategic importance of aquafeed and ingredient supply (Tacon *et al.*, 2021; FAO 2024).

Fish feed represents up to 60% of the fish farm production costs, while dietary protein accounts for almost half of the cost of aquafeed, resulting as the single most expensive feed component (NRC, 2011). Fishmeal is considered as "the gold standard" and the primary protein source of choice in aquafeeds, especially for the carnivorous and omnivorous fish species. The reasons for its superiority are high protein quality and content, high nutrient digestibility, and a general lack of anti-nutrients (Larsen *et al.*, 2012). Despite the advantages that fishmeal offers as an aquafeed ingredient, fluctuations in its production due to changes in wild fish catches (El Niño–Southern Oscillation) affect its availability and price (FAO, 2020).

## Alternative proteins in aquafeeds

The increased feed demand of the fast-growing aquaculture industry has been coupled with advanced efforts of replacing the fishmeal in fish feeds with proteins of plant, animal, and microbial origin in the past (NRC, 2011). Although land animal proteins are considered an economical alternative, their use has been restricted at times by feed regulations (NRC, 2011). Additionally, although microbial proteins have potential, they are, for the time being, limited in availability and remain rather costly (Ritala *et al.*, 2017). On the other hand, plant proteins are considered the main alternatives to fishmeal. The plant protein ingredients most commonly used in fish feeds worldwide are produced from soybean, corn, wheat, sunflower, and rapeseed (Hardy, 2010).

To be considered a candidate fishmeal replacer in fish feeds, an alternative ingredient must possess certain characteristics, such as high-quality protein content, high digestibility, and low levels of antinutritional factors (Gatlin *et al.*, 2007). In fact, during the past few years, many studies have shown detrimental effects on fish growth performance when high-plant diets are fed, especially to carnivorous fish species (Davies *et al.*, 1997; Francis *et al.*, 2001; Martin *et al.*, 2003; Panserat *et al.*, 2008).

Most of the alternative plant ingredients are well-known to contain several antinutritional factors. The antinutritional factors are biological compounds present in the ingredients, which affect the bioavailability and utilization of nutrients and impact intestinal physiology and absorption, and overall, the ultimate animal's metabolic performance. Important antinutrients commonly found in plant protein ingredients are protease inhibitors, non-starch polysaccharides, allergens, lectins, phytic acid, and saponins, among others (Francis *et al.*, 2001).

## Soy protein concentrate: A value-added soy product

Soybean meal is the most common protein source used in aquafeeds and animal diets (Hardy, 2010). Although it has a relatively high protein content, a favorable amino acid profile, and is produced sustainably, its use is limited by its high levels of antinutritional factors (Gatlin *et al.*, 2007). Numerous studies have shown that high soybean meal inclusion levels in the fish diets resulted in decreased growth performance and feed utilization (NRC, 2011). Baeverfjord & Krogdahl (1996) reported that high soybean meal levels in Atlantic salmon diets were the main cause of subacute enteritis (intestinal inflammation) induction in the distal intestine of the fish. Moreover, enteritis is considered a progressive and dose-dependent condition due to the antinutritional compounds found in soybean meal, which leads to slower growth and increased morbidity.

Soy protein concentrate is produced by a soybean refining process employing aqueous alcohol extraction, which removes a large amount of antinutritional compounds and has a minimum crude protein content of 60%. This process substantially increases the nutritional value of the SPC, resulting in a value-added soy product. Results from several studies showed that high inclusion of SPC can replace dietary fishmeal without negatively affecting fish performance and health. Kaushik *et al.* (1995) reported that replacement of fishmeal with SPC up to 100% in rainbow trout diets did not affect fish growth performance, nutrient utilization, or protein digestibility. Moreover, the incorporation of SPC in the diets of carnivorous juvenile cobia (*Rachycentron canadum*) up to 75% exhibited outstanding fish growth performance in terms of

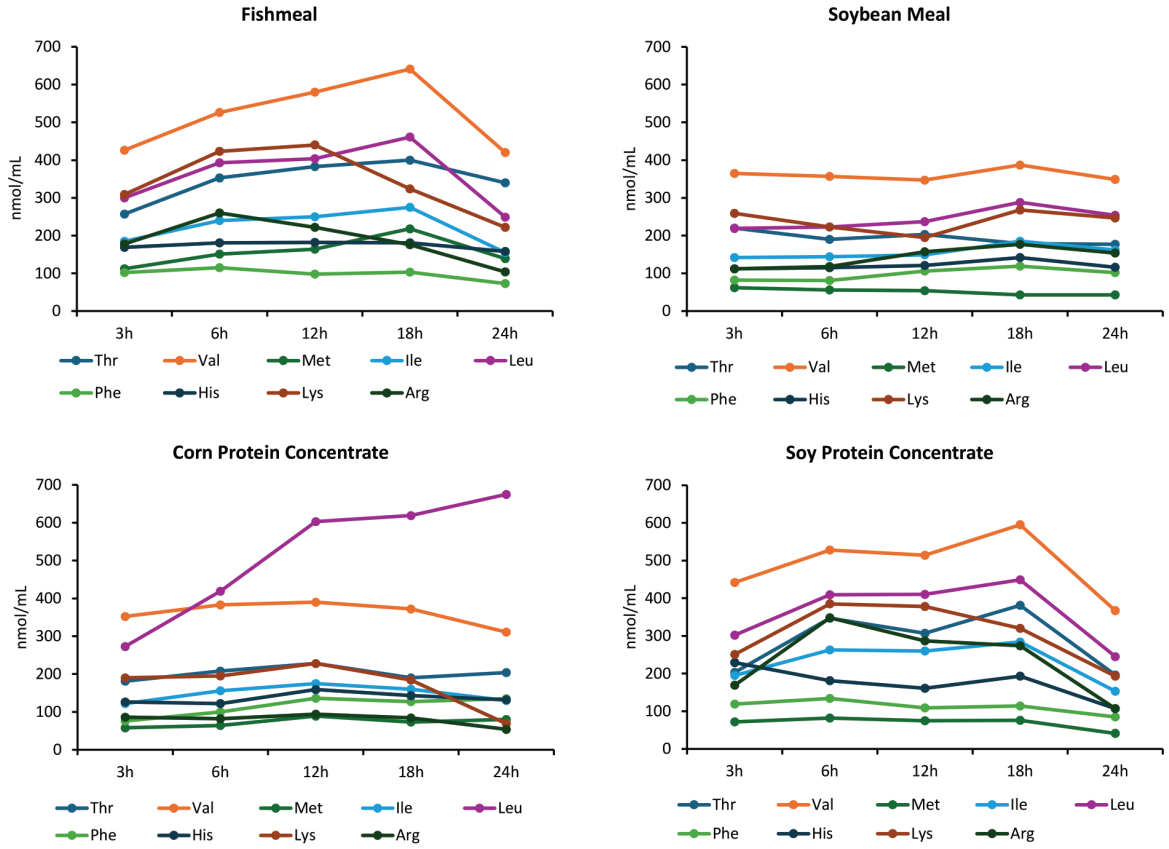


Figure 1. Free essential amino acid mean concentrations in blood plasma (nmol/mL) collected from the caudal vein of rainbow trout during a 24-hour period after force feeding fishmeal, soy protein concentrate, soybean meal, and corn protein concentrate (adapted from Brezas & Hardy, 2020).

weight gain, feed efficiency, specific growth rate, and survival (Salze *et al.*, 2010).

In line with the previous studies, Kalhoro *et al.* (2018) showed that the dietary substitution of the fishmeal up to 82.5 % SPC did not negatively affect the growth performance and feed efficiency of black sea bream fry (*Acanthopagrus schlegelii*) compared to a fishmeal-based diet. Similar results have been reported in Senegalese sole (*Solea senegalensis*) post larvae (85.6 mg wet weight) when fed an SPC-based diet (60% inclusion) (Aragão *et al.*, 2003).

Particularly noteworthy is the finding reported by Krogdahl *et al.* (2000), who demonstrated that when Atlantic salmon smolts (*Salmo salar*) were fed an SPC-containing diet and subsequently challenged by *Aeromonas salmonicida* ssp., they presented a significantly higher survival rate compared to the counterparts fed on a soybean meal-containing diet and a fishmeal-based diet.

Ultimately, a study conducted by Brezas & Hardy (2020), employing force-feeding of different ingredients in the rainbow trout and measuring at time intervals post-feeding plasma amino acids concentrations, showed that SPC post-prandially has a higher essential amino acid bioavailability pattern compared to other plant proteins but very similar to fishmeal (Figure 1). The study also concluded that, although it is a useful assessment tool for evaluating feed ingredient quality, protein and amino acid digestibility do not provide physiological insights into the bioavailability and metabolic utilization of dietary protein. This novel finding supports the view that SPC is considered one of the most promising and most widely used single ingredients in salmon diets over the past few years (Aas *et al.*, 2019).

## Conclusions

Overall, SPC stands out as one of the most promising plant protein ingredients for aquafeeds. Its higher protein content, lower antinutritional factors and high protein digestibility make it a strong option when looking for effective fishmeal replacement.

Available studies also show that SPC can support good growth performance and nutrient utilization, while offering amino acid availability patterns closer to fishmeal than many other plant proteins. For these reasons, SPC has become an important ingredient in modern aquafeeds and is widely used in the aquafeeds for carnivorous species.

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# Plant sterols power shrimp performance

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Over the past 30 years, shrimp farming has expanded exponentially, propelled by advancements in nutrition strategies, disease resistance, genetics, technologies and farming practices. This tremendous growth has also been driven by the world's growing appetite for seafood, while simultaneously increasing the industry's reliance on stressed marine resources of fishmeal and fish oil.

Approximately 90% of fishmeal and about 65% of fish oil produced annually is used in aquafeeds, with shrimp feeds contributing to 23% of fishmeal and 15% of fish oil usage. Although the global shrimp market has continually expanded at a rate of 4-5% per year, the annual supply of fishmeal and fish oil has remained relatively flat for the past 20 years. Furthermore, most of the wild "forage" fisheries from which fishmeal and fish oil are derived are harvested at or above their sustainable limits, and increasing harvests could have serious ecological impacts (EUMOFA 2025).

For the shrimp market to continue to expand and meet consumer demand, new solutions are critical. Feed ingredients such as insect meal, plant and algae-based proteins, modified plant and algae oils, and single-cell (yeast-based) proteins are currently being explored and utilized as cost-effective alternatives to traditional marine animal-derived feed ingredients.

## Cholesterol and shrimp physiology

Cholesterol is an essential nutrient for shrimp development, as it maintains cell membrane integrity,

aids in the digestion of dietary fats and serves as a precursor molecule to an assortment of steroid hormones that regulate molting, energy use and reproduction (Kanazawa, 2001). Unlike vertebrate animals, shrimp cannot synthesize cholesterol on their own. They need sources of it in their feed to support growth and healthy development (1-2.5 g/kg diet for optimal growth, depending on species and life stage).

Historically, feed formulators met the cholesterol requirements of shrimp by including plenty of animal-derived ingredients in feed formulations, such as fish and squid oils and fishmeal. Cholesterol concentrates have been another option (>90% purity, from sheep's wool grease), but the high cost of these concentrates generally limits their use to specialty shrimp feeds. Volatile supply chains and the ecological risks of overfishing have also put a strain on these traditional sources of cholesterol. The adoption of lipid emulsifiers in aquafeed formulations (e.g., lecithins, lysophospholipids, and bile acids) over the last 30 years has helped improve the bioavailability of cholesterol in diets, but these ingredients are not a substitute for cholesterol itself.

The current challenge lies in transitioning toward more sustainable or circular feed models without compromising the precise nutrient balance that shrimp require to thrive. An emerging solution that has not yet been widely explored is the use of plant sterols in shrimp feed.

## Plant sterols offer an alternative

Plant sterols are naturally occurring molecular compounds found in plants that are structurally similar to cholesterol. Several research studies have suggested plant sterols have similar growth and health-supporting effects on shrimp as animal cholesterol (Guo *et al*., 2020; Chen *et al*., 2023), but research on this topic is still limited.

A recent study evaluated whether plant sterols could effectively replace animal-derived cholesterol in shrimp grow-out feeds. Researchers examined the supplementation of practically formulated, extruded test diets with no additional sterols (basal diet), 1 g/kg of cholesterol concentrate (>92%), or 1 g/kg of plant sterols concentrate (>95%) and their effects on Pacific whiteleg shrimp (*Litopenaeus vannamei*) growth performance and body composition.

Experimental diets were formulated to reasonably emulate a commercial shrimp grow-out diet and were produced as 2 mm sinking pellets using a twin-screw extruder with a pre-conditioner. The trial took place in a clear-water recirculating aquaculture system with 30 120-L rectangular tanks, maintained at 30 ppt salinity and 28 °C. Pacific whiteleg shrimp seed stock (PL10) was acquired from a regional supplier and fed with a commercial nursery diet for three weeks before the start of the trial. After reaching approximately 0.5 g/shrimp in size, shrimp were distributed to the experimental tanks (25 shrimp/tank) and randomly assigned to one of the three

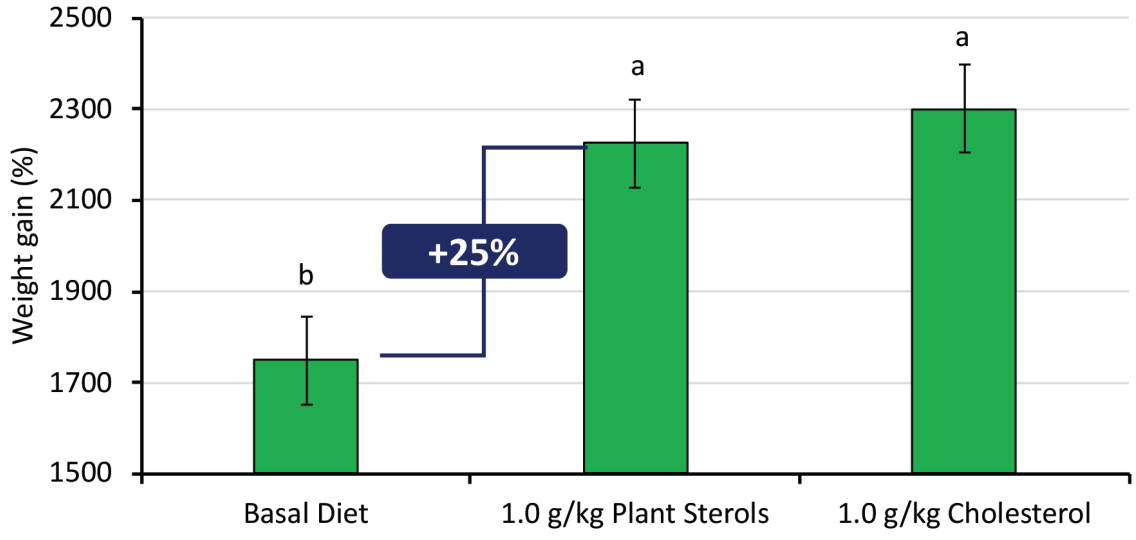


Figure 1. Total weight gain (%) of Pacific whiteleg shrimp after 62 days of feeding on practical test diets with supplemented plant sterols or cholesterol.

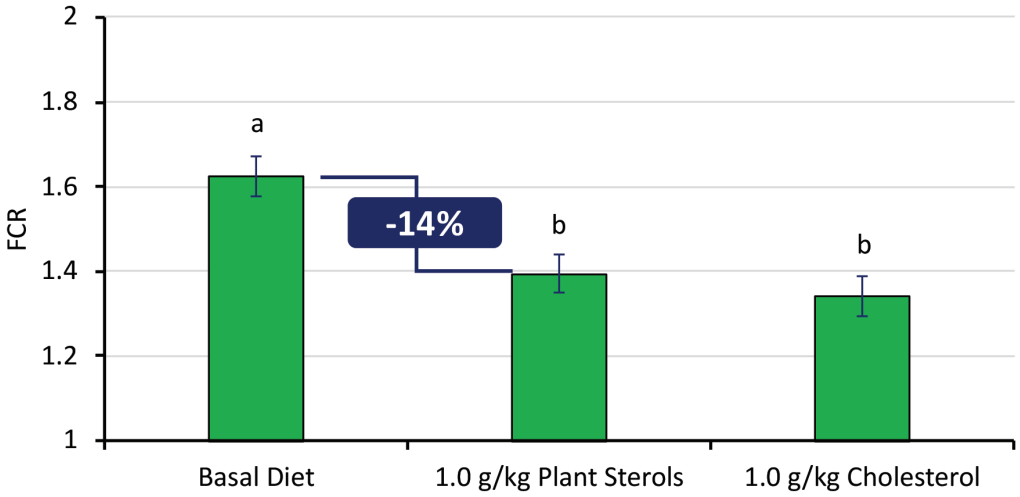


Figure 2. Feed conversion ratio (FCR) of Pacific whiteleg shrimp after 62 days of feeding on practical test diets with supplemented plant sterols or cholesterol.

experimental diet groups. Shrimp were fed the experimental diets on a semi-restricted feeding rate throughout the trial using automated feeders. All shrimp were harvested and weighed after 62 days of feeding on experimental diets and samples were taken from each tank for body composition analysis.

The results of the trial showed that supplementation of the basal diet with either sterols source led to significant improvements in weight gain and feed conversion ratio (FCR) during the feeding period (Figure 1, 2). There were no statistically significant differences in growth performance between shrimp fed plant sterols-supplemented and cholesterol-supplemented diets.

Shrimp fed with the plant sterols-supplemented diet had a similar concentration of cholesterol in hepatopancreas tissues as those fed with the cholesterol-supplemented diet (Figure 3), which suggests that shrimp can convert some fraction of the plant sterols mix into cholesterol to meet their needs. The results of this study suggest that plant sterols can support the same growth benefits as cholesterol in practically formulated shrimp feeds.

## Future opportunities for plant sterols

This study reinforces other scientific findings that indicate plant sterols offer an economical alternative for meeting the dietary cholesterol requirements of shrimp (Chen *et al.*, 2023; Guo *et al.*, 2020). Plant sterol concentrates are considerably lower in cost than cholesterol concentrates, and adding plant sterols to cholesterol-challenged formulations can reduce the feed cost per weight of shrimp produced (through FCR improvements). As cost and sustainable fisheries harvest concerns continue to push the replacement

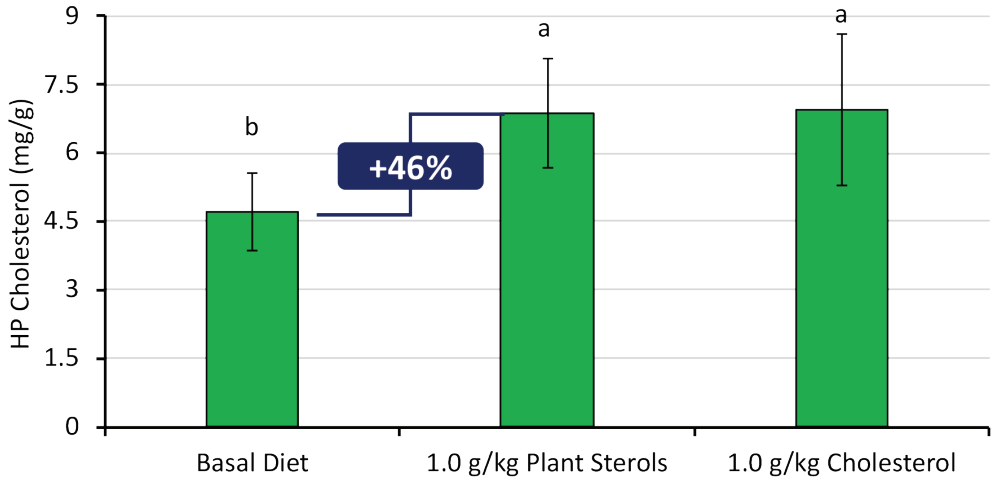


Figure 3. Hepatopancreas (HP) cholesterol concentrations (mg/g) of Pacific whiteleg shrimp after 62 days of feeding on practical test diets with supplemented plant sterols or cholesterol.

of marine animal-derived feed ingredients in shrimp diets, plant sterols can reduce the risks associated with cholesterol deficiency.

ADM has developed Plant Sterols AN, a highly concentrated plant sterols product (>95% total sterols) for shrimp feeds that helps address the concerns with marine animal-derived cholesterol. This dry powder has high processing stability, a highly stable formulation and a long shelf life. When incorporated in shrimp feeds, Plant Sterols AN can support rapid growth and efficient feed utilization while allowing formulators the flexibility to transition away from cholesterol-heavy ingredients.

By enabling formulators to reduce reliance on marine animal-derived cholesterol sources without compromising shrimp performance, plant sterols offer a practical step forward, helping producers improve feed efficiency, manage costs and reduce reliance on marine animal-derived cholesterol, all while supporting continued growth of the shrimp market.

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# Brightening your pigmentation results, naturally

**Joseph Bernot**
Nor-Feed

## Carotenoid family

Carotenoids are fat-soluble pigments belonging to the terpenoid family. Among the many carotenoids identified, only a few are used commercially. They play an important role in the metabolism of many organisms, including microorganisms, plants, algae, and animals. However, animals cannot synthesize carotenoids themselves, they must obtain them through their diet. In some species, carotenoids can then be modified and/or stored in tissues. In aquatic ecosystems, carotenoids mainly originate from phytoplankton and are transferred along the food chain to crustaceans and fish. In aquaculture, enriching feed with carotenoids is therefore of interest for certain species to ensure proper development and improve visual quality for consumers.

## Why are they colored?

The yellow to red color of carotenoids is due to a series of conjugated double bonds, known as chromophores. These absorb light in the visible spectrum, giving carotenoids their coloration. The hue and intensity depend on the chemical structure, particularly the number and position of carbon double bonds. These conjugated molecules are also responsible for the antioxidant properties of carotenoids, as they create a delocalized electron cloud that can neutralize reactive oxygen species. Among them, astaxanthin is the most effective antioxidant, partly due to its specific position within cell membranes. It is also the most efficient pigment for coloring fish and shrimp. However, astaxanthin is expensive and relatively poorly absorbed; only about 10% of dietary astaxanthin is taken up and retained by salmon. This absorption can be improved with emulsifiers or by using natural forms of astaxanthin rather than synthetic ones, although natural sources are more costly.

## The case of crustaceans

In crustaceans, carotenoids are not always in free form but are often bound to proteins in the shell or muscles, forming complexes called carotenoproteins. This binding alters their structure and results in different colors (blue, green, grey, or brown instead of yellow, orange,

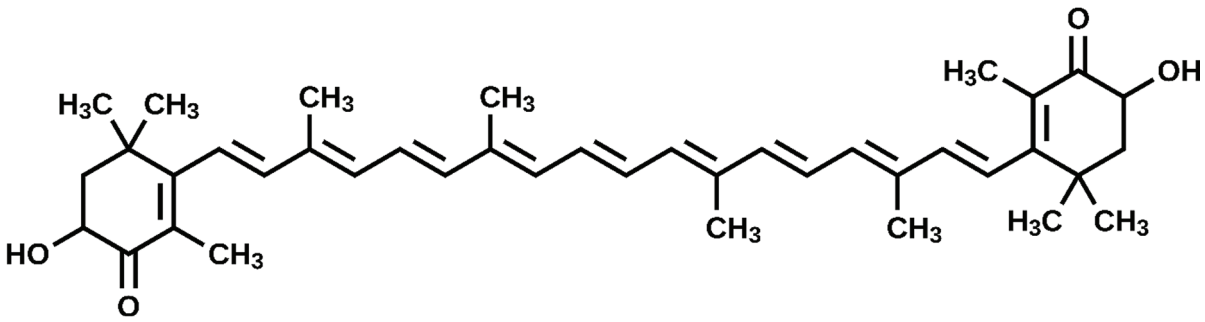


Figure 1. Astaxanthin molecule

or red). This explains the color of raw shrimp, which is a mix of free carotenoids with carotenoproteins. When cooked, heat denatures the proteins, releasing carotenoids and restoring their orange-red color. In shrimp, pigmentation intensity is less critical than in salmonids, although some markets still demand highly pigmented products. Pigmentation also influences price and can be negatively affected by storage and freezing.

### Declining pigmentation in salmon

The red-to-orange color of salmonids (salmon and trout) is a key quality criterion for consumers, as shown by various studies. However, in regions such as Norway, Chile, and Canada, pigmentation has declined in recent years despite increased astaxanthin supplementation. This indicates that increasing dosage alone is not sufficient and can lead to economic losses. In fact, the pigmentation system is complex, and various factors come into play. This decline may be linked to changes in feed composition (more plant-based ingredients) and increased fish stress, particularly due to sea lice treatments. Stress accelerates astaxanthin degradation, reducing pigmentation, and this process can continue during post-slaughter processing and storage of the fillet.

### Astaxanthin: Antioxidant or pigment?

Astaxanthin plays a role in neutralizing free radicals within the metabolism of aquaculture species, particularly due to its highly exposed position within the cell. In the process of neutralizing these radicals, astaxanthin itself becomes oxidized. This oxidation

produces other compounds whose sizes and structures vary depending on the type and intensity of oxidation. Changes in the number of double bonds in these compounds alter astaxanthin's ability to provide pigmentation, and as a result, its color can lose intensity in animal products. This process of oxidation and degradation affects all carotenoids to varying degrees. When astaxanthin or other carotenoids are used primarily as antioxidants, this indicates that they are performing their intended function. However, when they are used for pigmentation, oxidation and the resulting color loss are significant problems, particularly under high oxidative stress. We then end up with a loss of color intensity and uniformity.

## How to prevent pigment loss?

Color loss due to oxidation can occur during the fish's rearing phase, but may also continue after slaughter, within the flesh, throughout the period between processing and consumption. It has also been shown that pre-slaughter stress (e.g., poor handling or slaughtering practices) can significantly impact the color of trout fillets. In theory, adding a potent antioxidant to the feed alongside carotenoids could help neutralize free radicals before they interact with pigments, thereby limiting color degradation. While "technological" antioxidants are already used to protect pigments within the feed, a similar approach can be applied *in vivo* through "physiological" antioxidants to safeguard pigments during rearing and preserve them after slaughter. However, antioxidants differ in their cellular modes of action and in their effectiveness at protecting pigments *in vivo*. Astaxanthin, in particular, is highly prone to oxidation, making it difficult for many antioxidants to effectively protect it within the flesh.

## The power of grapes? Yes, if highly bioavailable

Studies conducted by Nor-Feed have shown that the use of grape polyphenols found in Nor-Grape® has the potential to improve pigmentation in salmonids and shrimp. Grapes are a fruit rich in polyphenols, which are mainly concentrated in the skin and seeds. The polyphenol composition of grapes, however, varies widely: it depends on the cultivar, soil composition, climate, geographic origin, and cultivation practices,

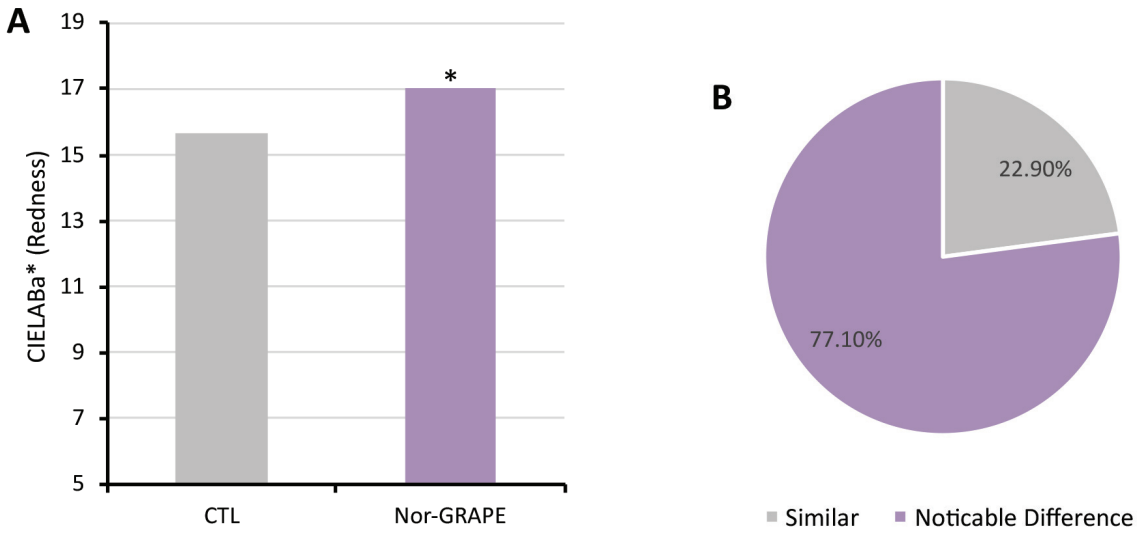


Figure 2. Pigmentation results: (A) Rainbow trout pigmentation (smoked fillet); (B) Visual comparison of smoked fillets by naive consumer panel.

as well as exposure to diseases, such as fungal infections. Nor-Grape® is a standardized dry grape extract containing polyphenols selected for optimal bioavailability, which means optimal diffusion into tissues. As a result, the polyphenols are absorbed and remain present in the flesh, where they can reduce free radicals before astaxanthin oxidation. Thus protected, astaxanthin retains its pigmentation potential.

### Similar effects in trout and shrimp

Nor-Feed specifically evaluated Nor-Grape® supplementation ("On-Top") in rainbow trout during the growing phase. For an equivalent astaxanthin level, trout receiving Nor-Grape showed a significant improvement in fillet coloration after slaughter and smoking, as measured by a Minolta colorimeter (increase in red values, CIELAB a*; Figure 2). These instrumental results were supported by visual assessment: in a blind comparison between control (CTL) and Nor-Grape groups, 77% of evaluators were able to clearly distinguish the more intensely colored fillets belonging to the supplemented group.

In shrimp, Nor-Grape also demonstrated positive effects on pigmentation after slaughter compared to a control group. In addition, pigmentation uniformity between individuals was improved. When comparing coloration before and after frozen storage, a significant decrease in redness (CIELAB a*) was observed in the control group, whereas this decline was not observed in the Nor-Grape group, indicating better color stability.

### A new lever in pigmentation strategies

In conclusion, polyphenols from Nor-Grape act at two levels: they enhance pigmentation intensity and help preserve it during storage. It therefore represents a complementary solution to approaches aimed at improving pigment absorption, such as emulsifiers, to optimize flesh quality and coloration. Its main advantage lies in its ability to protect pigmentation both *in vivo*, during farming, and post-harvest, during storage and processing (freezing, smoking).

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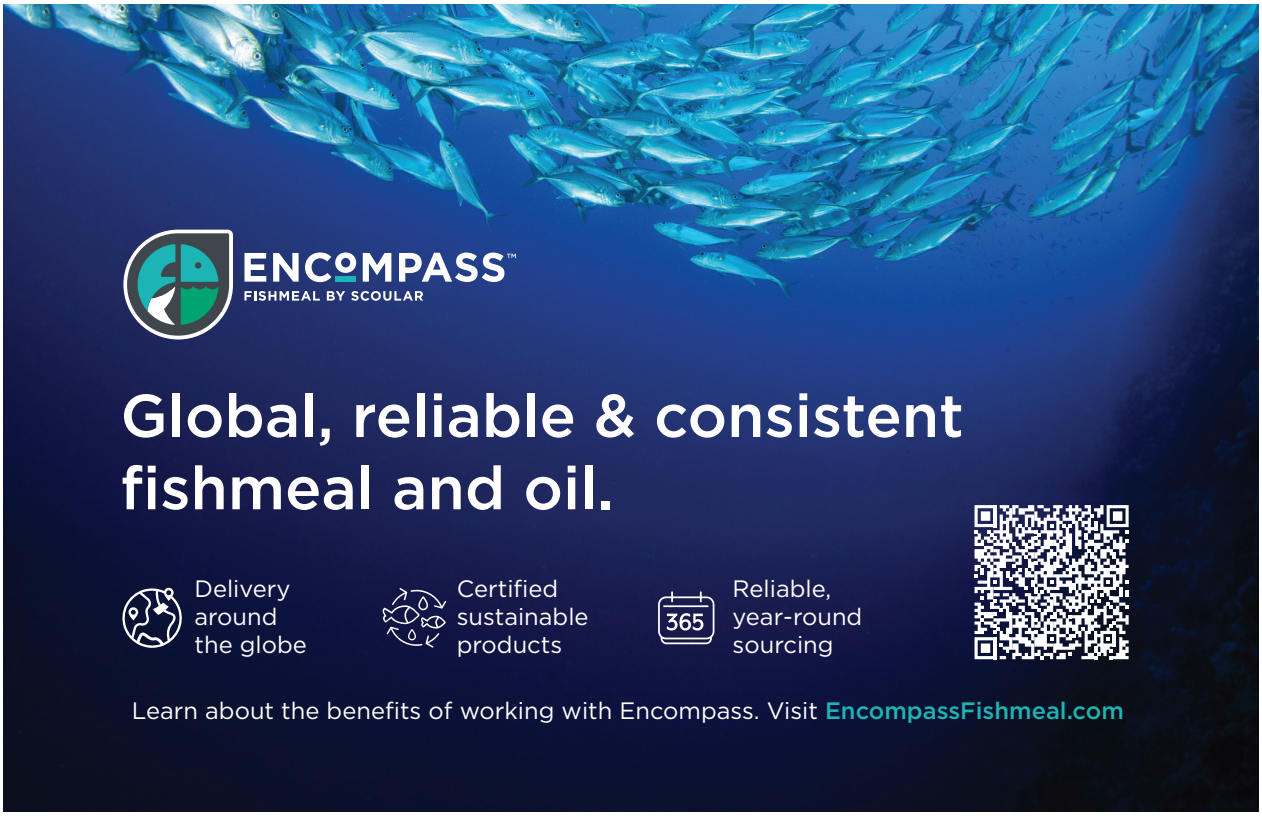

# Phytotherapy in aquaculture: Applications and issues

**Sagiv Kolkovski and Judith Kolkovski**
Nutrakol

With the continued expansion of cultured fish and shellfish species, aquaculture has become a major component of global animal protein production. It is currently the fastest-growing food production sector worldwide, with approximately 94.4 million metric tons produced in 2022 (FAO, 2024). With an average annual growth rate of approximately 7%, more than 63% of the global seafood supply now originates from aquaculture. However, this growth is accompanied by substantial health challenges. Major disease outbreaks such as White Spot Syndrome Virus (WSSV), Acute Hepatopancreatic Necrosis Disease (AHPND/EMS), and *Enterocytozoon hepatopenaei* (EHP) continue to affect the shrimp industry (Shrimp Outlook, 2025). In salmon farming, sea lice infestations are reaching record levels (Annual Sea Lice Performance Report, Manolin, 2024). Numerous additional bacterial, viral, fungal, and parasitic diseases continue to constrain production efficiency and sustainability.

## Antibiotics in aquaculture

The intensification of aquaculture systems has made infectious diseases a persistent and formidable constraint worldwide. Consequently, antibiotics and chemotherapeutic agents have become widely used across finfish, crustacean, and shellfish production systems.

Antimicrobial resistance (AMR) is now a major concern. As early as 1994, the American Society of Microbiology Task Force on Antibiotic Resistance stated: "The increasing problems associated with infectious diseases in fish, the limited number of drugs available for treatment and prevention of these diseases, and the rapid increase in resistance to these antibiotics represent major challenges for this source of food production worldwide."

Despite regulatory efforts, antibiotic misuse persists. Compounds such as fluoroquinolones, nitrofurans, and chloramphenicol are banned in many jurisdictions, yet residues continue to trigger import rejections in the US and the EU. In 2024, the US FDA recorded the highest seafood rejection rate in eight years due to drug residues.

Although FAO published *The Responsible Use of Antibiotics in Aquaculture* (2005), emphasizing the risks of misuse and resistance development, implementation remains inconsistent. Notably, in late 2025, Tasmanian salmon farms reportedly used approximately 700 kg of

Table 1. Herbal extracts used as growth promoters in aquaculture. The right column shows additional effects of these extracts in aquaculture. Compiled from Vijayaram *et al.*, 2023; Kolkovski, 2013.

| Botanical name | Organism | Additional biological effects |
|---|---|---|
| Turmeric (*Curcuma longa*) | Fish, crustaceans | Growth promoter, stress reducer, immunostimulant, hormonal booster |
| Clove (*Syzygium aromaticum*) | Fish | Growth promoter, stress reducer, immunostimulant, anesthetic |
| Thyme (*Zataria multiflora*) | Fish, crustaceans | Growth promoter |
| Pumpkin seed meal (*Cucurbita mixta*) | Fish, crustaceans | Growth promoter |
| Ashwagandha (*Withania somnifera*) | Fish, crustaceans | Antibacterial, growth promoter |
| Ginseng (*Araliaceae*) | Fish | Growth promoter |
| Garlic (*Allium sativum*) | Fish, crustaceans | Antibacterial, antiparasitic, growth promoter |
| Black cumin (*Nigella sativa*) | Fish, crustaceans | Growth promoter |

Table 2. Some examples of herbal extracts used as antibacterial remedies in aquaculture. The right column shows additional effects of these extracts in aquaculture. Compiled from Vijayaram *et al*. 2023; Kolkovski, 2013.

| Botanical name | Organism | Additional biological effects |
|---|---|---|
| *Daemia extenas* | Fish, crustaceans | Immunostimulant |
| *Psoralea corylifolia* | Fish, crustaceans | |
| *Adathoda vasica* | Fish, crustaceans | |
| *Acalypha indica* | Fish | |
| *Andographis paniculata* | Fish, crustaceans | Immunostimulant |
| *Azadirachta indica* | Fish | |
| *Artemisia vulgaris* | Fish, crustaceans | Antiviral |
| *Elephentopus scaber* | Fish, crustaceans | |
| *Melia azedarach* | Fish | |
| *Ocimum sanctum* | Fish | Antiviral, immunostimulant |

florfenicol within two weeks to manage *Piscirickettsia salmonis* outbreaks.

In intensive systems, disease-related losses are often normalized. “Natural mortality” of 10-25% during grow-out is commonly accepted. Marine finfish larval survival in hatcheries typically ranges between 5-40%, depending on species and husbandry practices. Mortality is multifactorial, involving environmental stressors, opportunistic pathogens, immature immune systems, and nutritional limitations.

Although system design, biosecurity, and husbandry improvements have reduced outbreaks, antibiotics are still used in some regions as therapeutic agents and, in certain cases, as growth promoters.

## Alternative therapy: Phytotherapy

Phytotherapy, the use of plant-derived extracts for therapeutic purposes, has been practiced for thousands of years. In countries such as China, India, and parts of Southeast Asia and Latin America, herbal medicine is mainstream. In Western systems, phytomedicine is increasingly recognized within complementary and integrative medical frameworks. The global herbal medicine market is estimated at USD 153-251 billion (2026), with projected annual growth rates of 8-21%.

Medicinal plants contain bioactive compounds, including phenolics, flavonoids, alkaloids, terpenoids, polysaccharides and proteoglycans.

These compounds exhibit antibacterial, antiviral, antifungal, immunomodulatory, digestive-supporting, and endocrine-modulating properties, as well as acting as growth promotors (Tables 1-4).

In aquaculture, strategies for disease prevention include improved environmental management, pathogen and disease management through system design and improved protocols, the use of specific pathogen-free (SPF) seed, immunostimulants (e.g., β-glucans), and probiotics and functional feeds.

Plant-derived compounds have demonstrated non-specific immunostimulatory effects in fish and shrimp. Numerous reviews (e.g., Banaee *et al*., 2025; Dadras *et al*., 2023; Fu *et al*., 2025) document their potential roles.

Plant products are often described as biodegradable, biocompatible, and relatively safe when properly dosed. Importantly, while microbial resistance to plant extracts is considered less common, resistance mechanisms to phytochemicals cannot be categorically excluded and require further research.

## Phytomedicine in aquaculture

Medicinal plants are well documented for antibacterial activity (Table 2). Bioactive compounds such as phenolics and flavonoids disrupt bacterial membranes, interfere with quorum sensing, and inhibit virulence factors.

Its use in aquaculture remains regionally variable. For instance, in West Java, Indonesia, 46% of fish farmers reportedly use fresh plant materials in ponds (Caruso *et al*., 2013). In India, commercial herbal feed additives are widely marketed and commonly used without restrictions in both intensive and extensive production systems. In China, herbal extracts are sometimes incorporated into reduced-antibiotic regimens to support immune function.

In Western aquaculture, phytochemicals are mainly positioned as nutritional supplements rather than therapeutic agents due to regulatory constraints.

Table 3. Herbal extracts used as antiviral remedies in aquaculture. The right column shows additional effects of these extracts. Compiled from Vijayaram *et al.*, 2023; Kolkovski, 2013.

| Botanical name | Organism | Additional biological effects |
|---|---|---|
| Sweet worm wood *(Artemisia annua)* | Fish | Antiparasitic |
| *Daemia extenas* | Fish | |
| *Psoralea corylifolia* | Fish | |
| *Adathoda vasica* | Fish | |
| *Andrographis paniculata* | Fish, crustaceans | Antibacterial, immunostimulant |
| *Melia azedarach* | Fish, crustaceans | |
| *Oenothera biennis* | Fish, crustaceans | Antibacterial |
| *Solanum trilobatum* | Fish, crustaceans | Antibacterial, immunostimulant |
| *Acorus calamus* | Fish, crustaceans | Antibacterial, immunostimulant |
| *Cassia alata* | Fish, crustaceans | Antiviral |
| *Psidium guajava* | Fish, crustaceans | |

Their application in high-intensity systems remains limited and often anecdotal.

## Single extract vs. mixtures

Most research evaluates single plant extracts due to ease of standardization and dose determination. However, traditional phytomedicine typically relies on multi-component formulations.

Potential synergistic mechanisms include disruption of pathogen membrane integrity, enhanced membrane permeability for active compound uptake, modulation of host immune response, and reduced toxicity through complementary compound interaction.

Synergism may enhance therapeutic efficacy beyond that of isolated compounds.

## Antiviral effects

Several plant extracts have demonstrated antiviral activity in shrimp and fish models (Table 3). For example, *Clinacanthus nutans* extract improved survival in shrimp challenged with Yellow Head Virus (YHV) (Direkbusarakom *et al.*, 1996). Extracts from *Aegle marmelos, Cynodon dactylon, Lantana camara, Momordica charantia*, and *Phyllanthus amarus* showed activity against WSSV. Several species of Indian herbs and plants such as *A. marmelos, C. dactylon, L. camara, M. charantia* and *P. amarus* showed strong antiviral activity against WSSV when extracted with organic solvents such as ether, chloroform, ethyl acetate, methanol and ethanol.

Numerous additional studies document antiviral and antibacterial effects (Elgendy *et al.*, 2024; Banaee *et al.*, 2025).

## Ectoparasites in aquaculture

Monogenean ectoparasites cause major economic losses in freshwater and marine aquaculture. Conventional treatments include copper sulphate, malachite green, formaldehyde, hydrogen peroxide, benzimidazoles, praziquantel and salt baths.

These treatments can be environmentally damaging, labor-intensive, and potentially toxic at incorrect dosages. Although some are banned in aquaculture, they are still commonly used.

Plant-derived compounds show promise as antiparasitic agents. For instance, essential oils from *Lippia sidoides* and *Mentha piperita* reduced monogeneans in Nile tilapia (Hashimoto *et al.*, 2016); *Ocimum gratissimum* eliminated gill parasites in tambaqui (Boijink *et al.*, 2016); and garlic, rosemary, ginger, tea tree, lang-du, Indian sandalwood, Macassar kernels, yam, and cinnamon extracts are just a few of the plant species found to have anthelmintic effects.

## Field verification

The effect of formulation of several different herbal extracts (NutraPara-Gone, Nutrakol) on fresh water carp, Rohu (*Labeo rohita*) and Catla (*Catla catla*) in commercial earthen ponds in India was tested in a field trial. The tests were conducted in 5 commercial earthen ponds, ranging in area from 22-40 acres and biomass from 25-90 MT (avg. fish weight range between 0.5-1.1 kg). The herbal remedies were daily mix or spray with the feed, either as powder (5 gr/kg) or liquid (8mL/kg) form, and fed to the fish for 4-8 days. Following the treatment, 50-70 fish were sampled from each pond and skin parasites were counted.

Table 4. Herbal extracts used as a hormonal booster in aquaculture. The right column shows additional effects of these extracts. Compiled Kolkovski, 2013; Kolkovski, 2018.

| Botanical name | Organism | Additional biological effects |
|---|---|---|
| *Withania ashwagandha* | Fish, crustaceans | Antibacterial, growth promoter |
| *Shatavari* | Fish | |
| *Tribulus terrestis* | Fish, crustaceans | Growth promoter |
| Garlic | Fish, crustaceans | Antibacterial, antiviral, immunostimulant |
| *Astragalus* | Fish, crustaceans | Immunostimulant |

Fish fed treated feed had an average reduction of 70% of skin parasites. The effect of the treatment lasts between 14 and 21 days. These results were on par with or better than the standard chemical treatment used to control parasites (a combination of several chemicals/ medications, varying by pond and grower). While not a "scientific" trial, this trial in "real-world" conditions demonstrates the potential anti-parasitic effect of herbal extracts.

## Stress reduction

Herbal compounds can act as antioxidants, scavenging reactive oxygen species and mitigating oxidative stress. Picrorhiza kurroa demonstrated anti-stress effects in *Penaeus monodon* (Citarasu *et al.*, 2006). Other herbs (e.g., *Astragalus membranaceus, Andrographis paniculata*) show similar properties.

## Hormonal modulation

Medicinal plants (Table 4) are also known to have hormonal boosting effects. Significant increase in fecundity, gonadal weight and reduced intermoult period was reported in *P. mondon* when the shrimp were fed a maturation diet containing *W. somnifera, Mucuna pruita, Ferula asafoetida* and *Piper longum* extracts (Kolkovski, 2018).

Currently, several hatcheries around the world are using a herbal extract mix (Nutrabrood Enhance, Nutrakol) specifically designed to boost and modulate the hormonal system in aquatic animals. The herbal extracts are used with out-of-season broodstock and/ or species with fertilization and gonadal development problems, such as groupers (low sperm motility and volume) and many other species.

Commercial maturation semi-moist diet (NutraFeed, Nutrakol) that included herbal extracts fed to *P. vanamei* resulted in an over 40% increase in total nauplii produced, with a 44% reduction in mortality compared to the standard fresh feed and nutritional boosters used (Kolkovski *et al.*, 2013). Similar results were found with Black tiger prawn *P. monodon*.

## Challenges and impediments

Several challenges limit the use of medicinal plants. Regulatory constraints in the EU, the US, and other jurisdictions require that herbal products making therapeutic claims undergo veterinary drug registration. Standardization is a major issue, as bioactive content can vary depending on geography, season, extraction methods, and storage conditions. Formulation complexity also presents difficulties, since the vast number of phytochemical combinations makes reproducibility challenging. In addition, there is limited mechanistic data, as rigorous, species-specific, dose-response studies are still insufficient.

## Conclusion

Plant-derived extracts represent a promising complementary strategy to antibiotics and chemotherapeutics in aquaculture. Properly standardized phytomedicines may enhance immune competence, improve stress resilience, reduce pathogen burden, and support reproductive performance.

However, large-scale adoption requires robust mechanistic research, standardization protocols, regulatory clarity, and controlled field validation trials.

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# Ample commodity supply, yet rising prices

**Mike Verdin**
CRM AgriCommodities

The world meal market is, on paper, well supplied. Global production of the eight major meals – copra, cottonseed, fish, palm kernel, peanut, rapeseed, soybean and sunseed meals – exceeded 400 Mt for the first time ever in the season 2025/26, according to the US Department of Agriculture, whose estimates set market benchmarks.

While demand is expected to hit a record of 396.8 Mt, it will lag output. That will allow stocks to swell to 24.0 Mt as of the close of the season, also an all-time high.

## Stocks are growing, but not excessively

So why have meal prices made a strong start to 2026? In Europe, prices of soybean meal rose by 12-13% in the first quarter, of palm kernel meal by 20%, and of rapemeal by 22%, according to CRM Agri commodity price data. Part of the answer is that prices had simply fallen too far. Absolute supply data do not tell the whole story. Relative levels count too, and in particular, the stocks-to-use ratio, which compares levels of inventories and demand.

The 2025/2026 stocks-to-use ratio of 6.1% – while high, above the average of 5.2% so far this century – is tighter than the record 6.4% set eight years ago. On that basis, meal prices warranted pressure, but not quite to the extent that drove Chicago soymeal futures to a nine-year low in October, and close to a 15-year low.

There is more than simple supply and demand mathematics involved in pricing, as evident in the volatility, which has remained a constant meal market feature. Analysis of soymeal, by far the biggest meal market, illustrates some of the other factors that can influence prices. Other meal markets have their own idiosyncrasies, too.

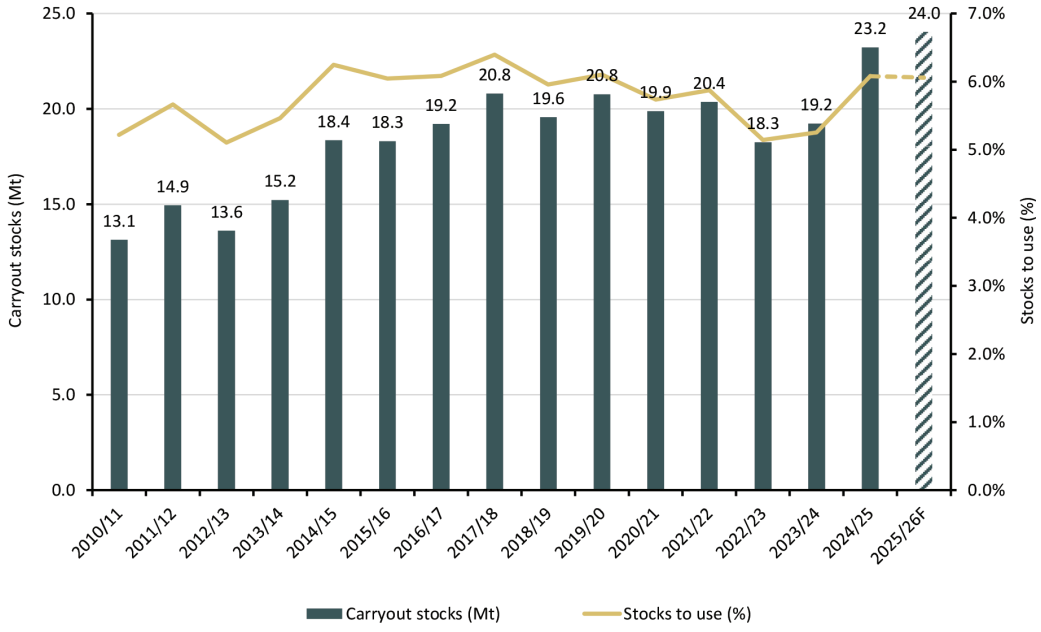


Figure 1. World supplies of major meals (USDA).

### Trade tensions reshape global flows

The decline in soymeal futures to their October low was spurred by pressure from both supply fundamentals, in terms of the increased confidence in a strong US soybean harvest, and from geopolitics, in China's refusal to buy US crop amid the countries' trade dispute.

The absence of China, the top soybean importer, from the US market forced soybean values lower to attract extra demand from other importers, as well as domestic crushers. That, in turn, implied extra US soymeal, weighing on values of that too.

These pricing dynamics reversed at the end of October, when President Trump and President Xi agreed on a trade deal that included Chinese commitments to buy US soybeans.

However, soymeal prices felt fresh pressure later in 2025 on a blistering US soy crush pace, and a surge of Canadian canola meal onto the international market. Canada, the top canola meal exporter, was left seeking other buyers after China imposed punitive import tariffs. Given that China had been responsible for more than one-third of Canada's canola meal exports, that was a big deal.

Rapemeal prices sank, weighing on other meals as well, as Canada sought new buyers, largely in Europe and the US. The EU, which has historically barely imported any Canadian canola meal, has bought 519.4Kt so far this season, far more than from all other origins combined.

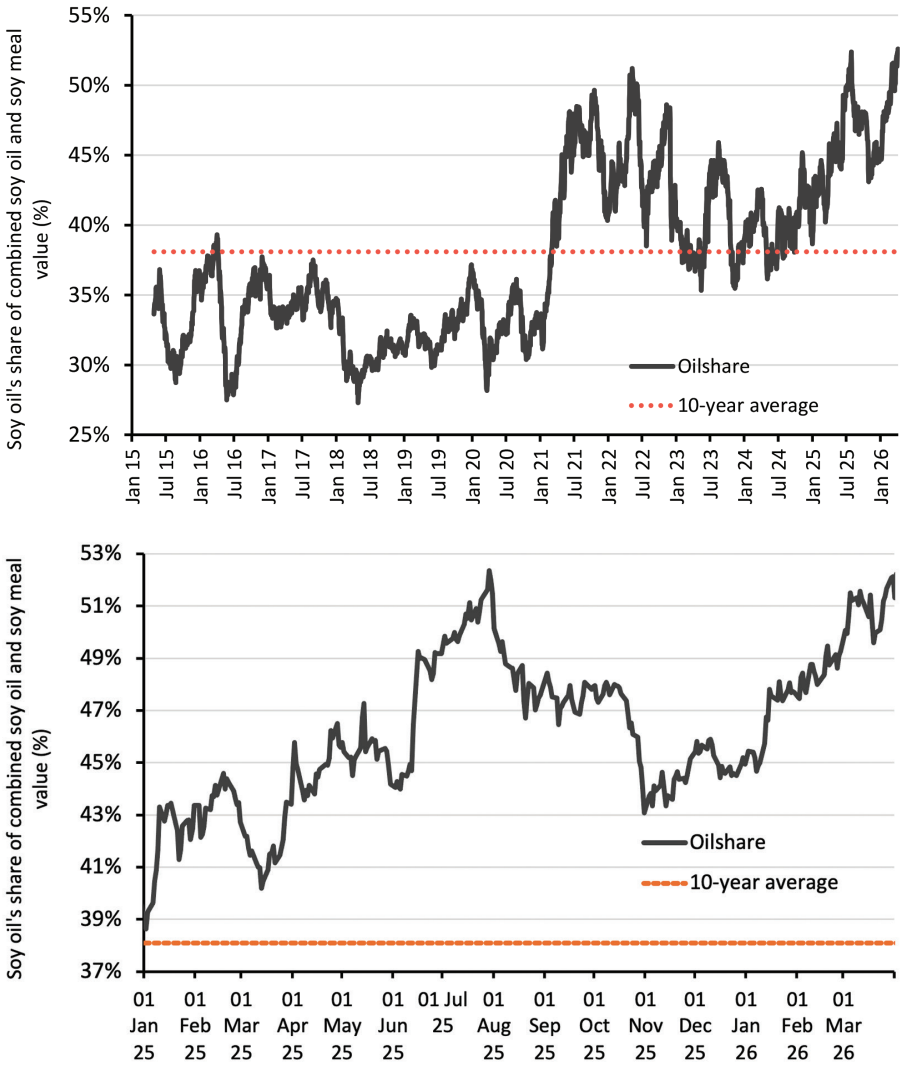


Figure 2. Xxxx

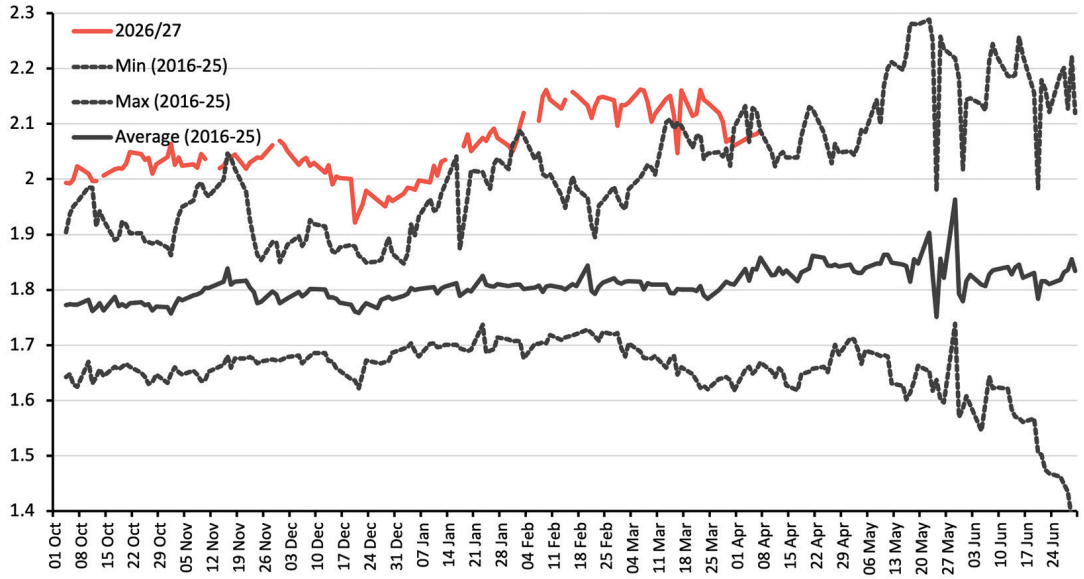


Figure 3. November canola vs December spring wheat price ratio, by harvest year.

Nonetheless, just as China-Canada relations weighed on meal prices late last year, they have now fueled this year's recovery. News in January that China was to ditch its punitive levies on Canadian canola called time on Canada's cheap canola meal offers, offering support through the complex.

## Iran war adds uncertainty to markets

Of course, the big geopolitical event of 2026 has been the Iran war, although for meal, this has been a relatively small deal, at least directly. Soymeal prices have a low correlation with crude oil, the bellwether of the conflict, compared with the likes of grains and vegetable oils. In fact, the Middle East conflict could be seen as a demand threat, given that the region accounts for 10% of global meal imports.

Vegetable oils, linked to crude oil via their use in making biodiesel, have found more price support than meal from the war. For soy oil, buoyancy lent by the crude oil rally has expanded to 52% its share of the combined value of the two soybean processing products. That is well above the 10-year average of 38%, and indeed among the highest figures ever, exceeding even the level reached in May 2022 amid the oil price surge following Russia's invasion of Ukraine.

## Export squeeze tightens Argentine soymeal supply

The ratio might already be higher still this time were it not for extra support that soymeal prices are receiving, not just by rapemeal but a squeeze on Argentina's exports.

Soymeal exports by Argentina, the top meal shipper, in the December-to-February period fell by 17% year on year to 5.0Mt, reflecting a squeeze on supplies of soybeans to crush.

Despite a strong 2025 harvest, Argentina's soybean stocks have been drained by rising exporters, after the government temporarily suspended export taxes in September. This encouraged a surge in demand for Argentine soybeans, notably from China.

Argentina's soybean exports in the last four months of 2025 soared to 6.8Mt, from 542.1Kt a year before. Soybean imports, meanwhile, this year set a February record of 831.4Kt as the country strived to rebuild its supplies.

## Not all protein meals follow the same path

Prices of the different meals can diverge, depending on market variations. Prices of fishmeal, for instance, which has very different supply dynamics, were rallying in October – even as soy meal prices were at nine-year lows – on jitters over plans for a 70% cut in the North East Atlantic whiting quota.

Fishmeal values may find support ahead, too, assuming the onset of an El Niño, as meteorologists foresee. The raised Pacific surface water temperatures associated with the weather pattern encourage anchovy shoals to swim deep, curtailing the catch of a key source of fishmeal.

### Robust supply outlook, but risks remain

For soymeal, which accounts for 70% of world meal supplies, and rapemeal, a further 12%, supply outlooks appear more promising.

Brazil's soymeal supplies are seasonally swelling, with the 2025/26 soybean harvest – a record one – now some 80% done. Its soymeal exports rose by 20% year-on-year last month to set a March record of 2.7Mt, according to merchants.

With Argentina's soybean harvest just starting, its soymeal exports should soon begin a seasonal recovery, albeit that the crop is expected to fall some 3Mt year on year, to 48Mt, due to a switch in plantings to corn.

Sowings are very much in focus in the US, where April opens the Midwest spring planting window, and where soybean area is expected to bounce from last year's six-year low of 81.2M acres, reaching 84.7M acres, according to the USDA.

Expansion could prove even larger, potentially putting a record harvest in sight, if the boost to fertilizer prices from the Iran war lifts further the oilseed's appeal. Soybeans, which fix their own nitrogen from the atmosphere, have lower nutrient needs than corn, meaning they are often favored by farmers when fertilizer costs are high. Sunflowers, another low-input crop, could gain area too this spring from corn in Europe and the Black Sea.

Meanwhile, the outlook for rapeseed supplies is buoyed by high hopes for this year's EU harvest – forecast topping 20.0Mt for a second successive year, for the first time in more than a decade – and potential for larger sowings in Australia and Canada too.

Certainly, rapeseed prices look enticing for growers. Canola is worth, unusually, more than twice as much as spring wheat per tonne, on a new crop basis, well above the average of 1.8.

With the outlook for feedstock supplies appearing robust, that for meals does too, especially if strong demand for vegetable oils, whetted by energy needs, continues to drive crush margins.

Still, as the last few months have shown, there is plenty of scope for the outlook to miss expectations. Crops could yet suffer setbacks – the prospect of El Niño hardly augurs well for Australia's 2026/27 harvests – even before considering risks posed by geopolitical uncertainty.

With markets likely to stay volatile, meal users should be presented with opportunities to buy meal at attractive levels, but sustained opportunities will be less likely while war and other geopolitical uncertainties overshadow markets.

**More information:**
CRM Agricommodities (crmagri.com)

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# Feed formulation under temperature stress in the Mediterranean area: From baseline nutrition to prevention as a risk management investment

**Sara Magalhães, Tiago Aires**
Aquasorgal

Climate change is increasingly recognized as a critical factor shaping the future of aquaculture production. Among the environmental parameters influencing cultured species, temperature stands out as the primary abiotic driver of fish physiology, controlling metabolic activity, growth, immune competence and reproductive performance. Fish are ectothermic, so their metabolism is directly influenced by water temperature, with even small deviations affecting feed intake, digestion and energy use.

Recent satellite observations confirm that the Mediterranean Sea is experiencing a sustained warming trend, reinforcing concerns about the impact of climate change on aquaculture production systems. Analysis of satellite-derived sea surface temperature data from 2003 to 2019 shows an average increase of approximately 0.040 °C per year, corresponding to nearly 0.4 °C per decade. Between 2005 and 2019, Mediterranean Sea surface temperature increased by approximately 0.85 °C, highlighting the rapid pace of environmental change already affecting the region (Garcia-Monteiro *et al.*, 2022). Importantly, warming trends are not uniform throughout the year. Seasonal analysis shows that the strongest warming occurs during summer, with temperature increasing by around 0.070 °C per year, followed by winter warming of approximately 0.040 °C per year.

As climate change progresses, the frequency and magnitude of extreme temperature events, including both heatwaves and cold spells, are also increasing in many aquaculture regions, intensifying thermal stress during critical production periods. Indeed, surface water temperatures in southern Mediterranean areas may exceed 30-32 °C during summer, while in some regions, winter temperatures may drop close to 10 °C during cold episodes.

Mediterranean aquaculture, which relies heavily on marine species such as European seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*), is therefore particularly sensitive to temperature fluctuations that have direct implications on fish welfare, farm productivity and disease susceptibility. Consequently, aquafeed formulation is increasingly expected to play a role not only in maximizing growth but also in supporting physiological resilience under variable environmental conditions.

## Temperature fluctuations and physiological stress

Temperature changes affect fish through a cascade of physiological responses that can ultimately influence performance. Exposure to temperatures outside the optimal thermal window triggers a stress response involving endocrine, metabolic and immune systems (Islam *et al.*, 2022). Thermal stress prompts neuroendocrine responses, leading to the release of cortisol that mobilizes energy and adjusts physiological functions. This is followed by metabolic disturbances, oxidative stress and altered nutrient use, increasing

energy demands to maintain homeostasis. Prolonged exposure results in reduced growth, impaired immunity and higher susceptibility to disease.

For Mediterranean species, the direction of thermal stress is often species-specific. Gilthead seabream tends to experience greater physiological stress during winter cold periods (winter syndrome disease), while European seabass is more vulnerable to extreme summer temperatures. Both scenarios can lead to decreased feed intake, reduced growth rates and heightened disease risk.

### Temperature stress and disease susceptibility

Thermal stress has a strong influence on host–pathogen interactions, as deviations from the optimal thermal range can alter fish immune competence while simultaneously enhancing the virulence and proliferation of aquatic pathogens (Okon *et al*., 2024).

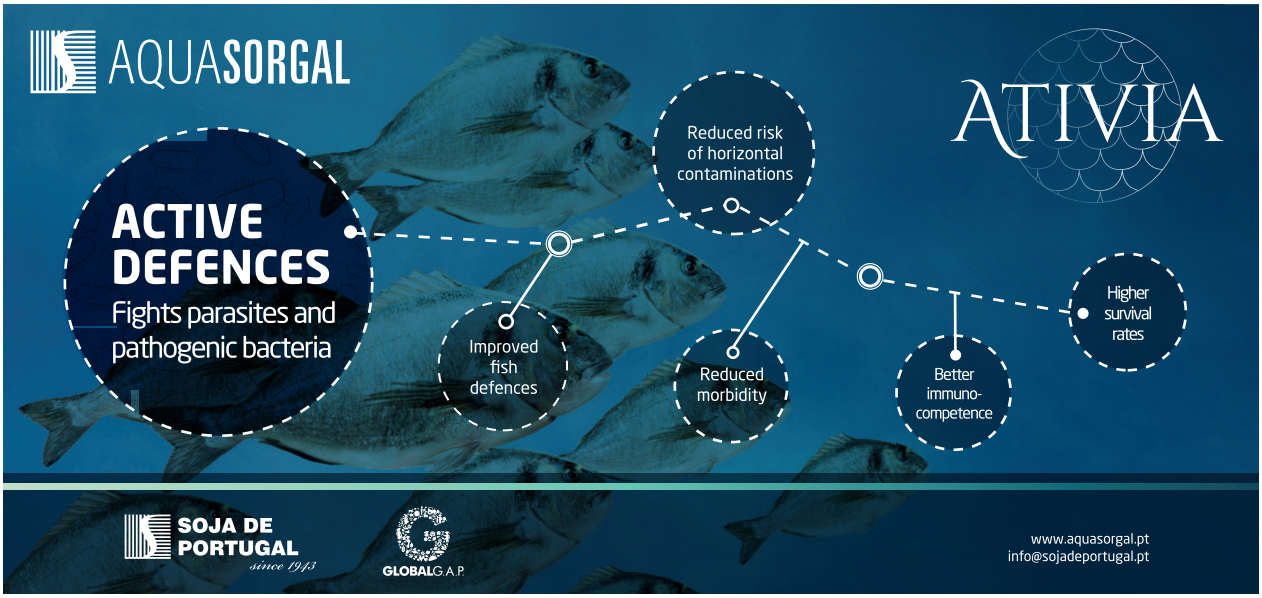
Cold stress is frequently associated with immune suppression. Reduced metabolic activity and lower feed intake during winter limit the availability of nutrients required to sustain immune defenses, creating a mismatch between host resistance and pathogen pressure, particularly when certain bacterial agents remain active. Conversely, elevated temperatures accelerate metabolic rates and oxygen demand while reducing dissolved oxygen availability, increasing physiological stress and compromising homeostasis. Under these conditions, pathogen replication and transmission are often enhanced, further weakening the fish's ability to mount an effective immune response. In addition, temperature fluctuations can disrupt the synchrony between host defense mechanisms and pathogen life cycles, increasing the likelihood of disease outbreaks.

These processes are especially relevant in Mediterranean aquaculture, where seasonal temperature transitions are closely linked to recurring disease events in seabream and seabass. Gram-negative bacteria remain the predominant pathogens, notably *Vibrio* spp., *Photobacterium damselae* subsp. piscicida and *Aeromonas* spp. (Massaccesi *et al*. 2026), while *Lactococcus garvieae* has emerged more recently as a major Gram-positive threat associated with severe septicemia and high mortalities (Salogni *et al*., 2024; González-Martín *et al*. 2026). In parallel, parasitic diseases represent an equally important constraint. Key species such as *Sparicotyle chrysophrii* in seabream, *Enteromyxum leei, Ceratothoa oestroides* and *Amyloodinium ocellatum* are widely distributed and can significantly impair growth, feed efficiency and survival (Oidtmann *et al*., 2024).

Effective mitigation requires an integrated approach combining environmental management, health monitoring and preventive nutritional strategies to enhance resilience under thermal fluctuations.

### Nutritional resilience as a mitigation strategy

Nutrition is a key tool to support fish resilience under challenging conditions. Diet quality and nutrient



availability support increased energy demand, improving physiological fitness. Feed formulation must therefore consider seasonal variations in feed intake, shifts in metabolic requirements and the need to sustain immune function and gut health, with a growing focus on robustness and consistent performance beyond optimal conditions. Increasing environmental unpredictability is progressively shifting preventive nutrition from a perceived cost into a strategic investment in risk mitigation.

The foundation of any resilient feed formulation lies in the careful selection of macroingredients. Ingredient digestibility, nutrient availability and raw material stability are all critical parameters that influence fish performance, particularly under stressful conditions. When dealing with carnivorous species like seabream and seabass, the formulation must prioritize high levels of high-quality animal protein from marine and poultry (if this is an option) rather than vegetable meals, to ensure higher feed digestibility and retention of essential nutrients.

When water temperatures decline, digestive enzyme activity and gut motility may decrease, potentially reducing nutrient assimilation. Under these circumstances, highly digestible protein and lipid sources, as well as balanced amino acid and fatty acid profiles, become particularly important. Conversely, during periods of high temperature, metabolic rates increase and energy demands rise. Feeds must therefore provide adequate energy density without compromising nutrient balance or gut function.

Consistency in ingredient quality is also essential. Variability in raw material composition or the presence of anti-nutritional factors can exacerbate physiological stress and reduce feed efficiency. Maintaining stable and predictable feed quality becomes a key component of risk management.

Beyond basic nutrient supply, functional ingredients are increasingly incorporated into aquafeeds. Several categories of functional additives have gained attention in recent years, including antimicrobials, anti-inflammatory agents, immunostimulants, digestive enhancers and antioxidants, to support main physiological functions.

Early life stages in fish, particularly larvae and juveniles, are widely recognized as highly sensitive phases, often associated with elevated mortality rates and increased vulnerability to environmental and biological stressors. For this reason, feeds designed for these stages traditionally incorporate higher levels of functional support, targeting gut development, immune competence, skin and gills protection and overall robustness. However, growing evidence and field experience suggest that extending this functional approach beyond early stages can provide significant benefits in seabream and seabass species. Maintaining targeted nutritional support during the juvenile phase – up to approximately 100-120 g – appears to contribute to improved gastrointestinal functionality and more effective defense against different kind of pathogens, with consequent repercussions in better growth and survival.

From a formulation perspective, this has led to a broader reconsideration of how functionality is integrated across the entire production cycle. Rather than being limited to early-stage diets, there is increasing recognition that even grow-out feeds should incorporate baseline functional strategies. These include the use of additives and ingredients involved in preventing dysbiosis and promoting a balanced gut microbiome, favoring beneficial bacterial populations over opportunistic and pathogenic strains, which is essential to sustain nutrient absorption and immune competence under stress conditions.

Field observations support this approach, with producers reporting improvements in survival, reduced morbidity and greater consistency in biomass output when functional strategies are applied throughout the production cycle. This reinforces the importance of adopting preventive, nutrition-based strategies as part of a broader health management framework. Investing in a consistent, well-formulated feed throughout the production cycle can, in fact, enhance return on investment and support more profitable aquaculture farms.

Addressing the challenges posed by temperature-driven stress and disease dynamics requires sustained investment in research and innovation. The development of targeted nutritional solutions, including those aimed at specific pathogens, is becoming increasingly relevant. In this context, the selection of ingredients is evolving beyond their basic nutritional value towards their functional potential. Bioactive peptides derived from marine and animal hydrolysates, medium-chain fatty acids such as lauric

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acid from insect-based ingredients and selected phytogenic compounds have shown promising roles in supporting gut health, decreasing pathogenic virulence, modulating immune responses and improving overall resilience during periods of environmental instability.

Such strategies align closely with a One Health perspective, where animal health, environmental sustainability and production efficiency are addressed in an integrated manner, reducing reliance on therapeutic interventions while enhancing the robustness of aquaculture systems.

*References available upon request.*

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# Quality over quantity: High-density microbial protein delivers

**Robert Mansfield**
Aerbio

Supply constraints and price volatility associated with fishmeal continue to limit the growth potential of the aquaculture industry within current feed formulation regimes. Fishmeal remains widely used in shrimp and other aqua diets due to its high digestibility, balanced amino acid profile, and ability to reliably deliver strong growth performance. Among other protein sources, those that best replicate these nutritional and functional characteristics of fishmeal are generally able to integrate most easily into commercial feed formulations and manufacturing pipelines.

Plant-derived proteins, including soybean meal and corn gluten meal (CGM), are widely adopted due to their availability and cost competitiveness. However, these typically exhibit lower digestibility than fishmeal and less favorable amino acid profiles, which can constrain feed efficiency and growth performance. While advances in the processing of plant-protein concentrates have led to relative improvements in the digestibility and reduced anti-nutritional factors, functional limitations persist and negatively impact the performance of feeds, especially at higher inclusion levels. Diets that are high in plant protein continue to be associated with poorer growth performance outcomes and reduced feed efficiency, and are under increasing scrutiny related to their broader impacts on aquaculture systems, such as reduced product quality (fillet texture, etc.) and lowered water quality.

Fermented microbial products represent an exciting emergent class of ingredients capable of delivering high performance in aquaculture applications. Although sometimes painted as a single class of nutritionally similar products, in reality, there is immense diversity across the product category, driven by both the optionality in the microbe species and strain selection, and the variety of possible approaches to up- and downstream processing in their production.

The evolutionary diversity across microbial species is greater than that which exists between plants and animals combined, and so it is not surprising that the inherent nutritional, physical, and functional qualities of the associated products vary broadly also. Consequently, in the evaluation of new microbial protein ingredients in particular, it is crucial to carefully evaluate each new product individually to ensure its value is maximized.

This study evaluates a high-protein *Cupriavidus necator*-based microbial biomass, Proton™ (Aerbio), as a replacement for fishmeal in diets for Pacific white

shrimp (*Litopenaeus vannamei*), with a focus on feed efficiency and standardized growth performance. The ingredient was produced using a sugar-free "gas fermentation" platform, wherein carbon dioxide, hydrogen, and oxygen were added as the primary carbon and energy sources for the microbes in the production process.

## Materials and methods

A 60-day feeding trial using juvenile Pacific white shrimp (*Litopenaeus vannamei*) under controlled tank conditions at APOTEC Vietnam, with experimental design, oversight, and data analysis provided by aquaculture nutrition specialists, Wittaya Aqua. Seven diets were randomly allocated in quadruplicate, with 20 shrimp stocked per tank and fed multiple times daily according to standard commercial practices.

A commercial-type basal diet containing 25% fishmeal was formulated to contain 40% crude protein and 7% lipid and to meet established nutritional requirements for Pacific white shrimp. Six experimental diets were nutritionally balanced with the basal diet for crude protein and lipid levels across treatments, from which fishmeal was partially replaced by four graded inclusion levels of Proton™ (20%, 15%, 10%, 5% fishmeal) or by corn gluten meal (20% and 10% fishmeal) in two reference diets. The Proton™ ingredient contained >85% crude protein (Nx6.25 basis), compared with ~65% for fishmeal and ~63% for corn gluten meal.

Performance was evaluated using feed conversion ratio (FCR), Wittaya Aqua Growth Index (GI), apparent digestibility coefficients (ADC), and nutrient retention.

## Results

***Feed efficiency and standardized growth performance***

Relative to the fishmeal control diet (25% fishmeal; 0% Proton™), feed conversion ratio (FCR) was enhanced in diets containing the Proton™ ingredient. Biological FCR decreased by ~7%, from 1.28 in the control to below 1.20 with the most efficient Proton inclusion, corresponding to the 10% fishmeal and 11.43% Proton™ formulation. Across all Proton™ treatments, including the highest tested inclusion level of 15.24% Proton™ with 5% fishmeal, which yielded an FCR of 1.23, a linear regression analysis indicated a trend towards improved FCR with increasing inclusion level ($p$=0.06).

A clear dose-response relationship was observed between Proton™ inclusion and growth performance. Benchmarked using the Wittaya Aqua Growth Index (GI), a significant improvement was observed in the highest-performing treatment (10% fishmeal; 11.43% Proton), where GI increased from 3.46 in the

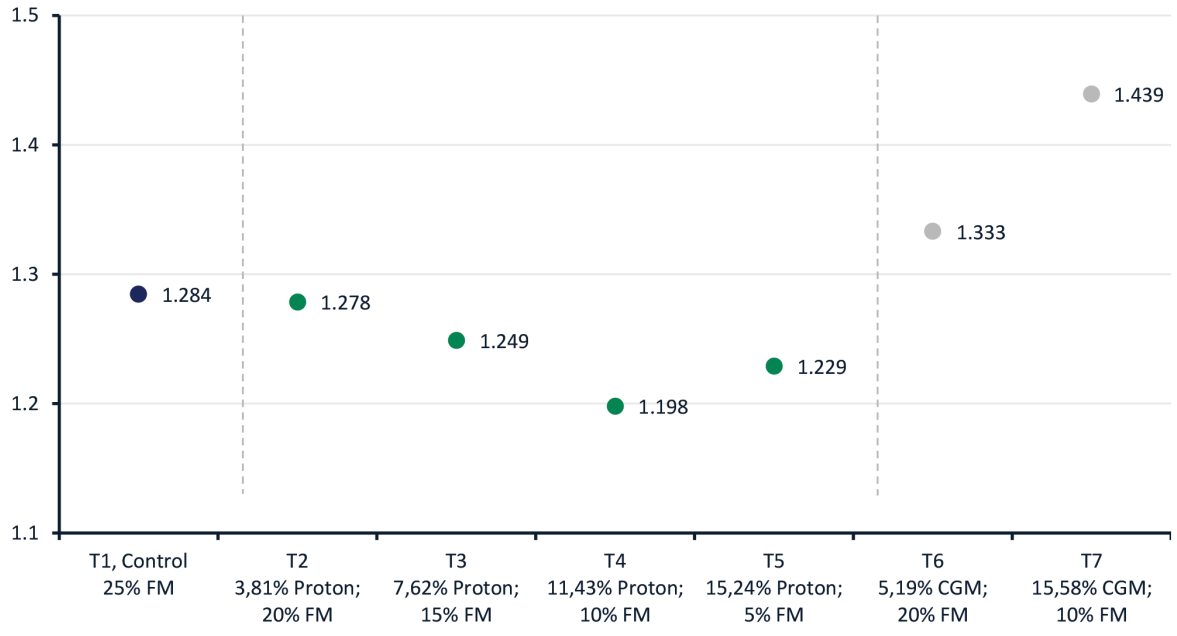


Figure 1. Measured feed conversion ratio, diet average.

control to 3.71 ($p$=0.01). Linear regression confirmed a significant positive relationship between Proton™ inclusion and GI ($p$=0.01).

In contrast, shrimp fed diets containing corn gluten meal (CGM) showed progressive deterioration in performance with increasing inclusion. FCR increased to 1.33 and 1.44 at CGM inclusion levels of 5.19% and 15.58%, respectively, while GI declined to 3.27 and 2.96, indicating inferior feed efficiency and growth performance relative to both the control and Proton™ diets.

***Digestibility***

Crude protein apparent digestibility coefficients (ADC) for the Proton™ diets remained comparable to the fishmeal control across all inclusion levels, indicating similar availability of protein and amino acids. In contrast, CGM diets exhibited significantly reduced digestibility, with crude protein ADC decreasing by >6% and >16% at inclusion levels of 5.19% CGM and 15.58% CGM, respectively.

These results indicate that, relative to the fishmeal control, performance improvements observed with Proton™ were not substantially driven by differences in protein digestibility, but rather by more efficient utilization of the nutrients provided. In contrast, reduced performance in CGM diets was associated, in part, with lower digestibility.

## Discussion

Replacing fishmeal with Proton™ improved feed efficiency and standardized growth, with the strongest responses at 10-15% inclusion, indicating an optimal range for maximizing performance.

Proton™'s high crude protein content delivers significantly greater nutrient density on a kg/kg basis than fishmeal, enabling more precise and efficient formulation. This allows target nutrient specifications to be met at lower inclusion levels, increasing flexibility within the formulation matrix. As diets were formulated to be iso-nitrogenous, the observed improvements cannot be attributed to total protein supply and highlight the importance of protein quality over quantity.

Digestibility of Proton™ was comparable to fishmeal, confirming similar availability of protein and amino acids. This indicates improvements in post-absorptive nutrient utilization as the likely driver of the improved performance and growth outcomes.

In contrast, corn gluten meal showed reduced digestibility and lower performance at higher inclusion levels, highlighting the limitations of some plant-based proteins and reinforcing the importance of both nutrient availability and effective utilization in shrimp diet formulation.

From an industry perspective, these results position microbial protein as a high-density, consistent ingredient that supports precision formulation, reduces reliance on fishmeal, and delivers reliable performance within an optimal inclusion range. Its value is therefore maximized as a functional component of a balanced diet, rather than through maximizing replacement levels alone.

## Conclusion

The *C. necator*-based microbial protein ingredient, Proton™, effectively replaced fishmeal while improving feed efficiency, standardized growth performance, and nutrient utilization in Pacific white shrimp.

These results highlight Proton™'s value as a high-performance alternative protein ingredient, demonstrating significant potential to support improved feed formulation efficiencies and on-farm production outcomes.

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# Embracing holistic formulation strategies to maximize positive outcomes in aquaculture nutrition

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## Setting the scene

Aquaculture nutrition has progressed over the past few decades. We now have a much stronger understanding of species-specific nutrient requirements, and the range of commercially available ingredients has expanded. Yet, despite this progress, many of the research approaches used today still reflect an earlier era. The industry has moved forward, but in many cases, our experimental strategies have not kept pace.

We are now formulating feeds in a context defined by ingredient variability, cost pressure, sustainability expectations, and increasingly complex supply chains. At the same time, aquaculture continues to diversify across species and production systems. These realities demand a more integrated approach to feed formulation. However, much of the research effort remains focused on evaluating single ingredients in isolation, often with the aim of replacing one ingredient with another.

## One-to-one replacement

For years, the industry has pursued replacing fishmeal or fish oil with alternative ingredients. This has driven a large body of research, often centered on demonstrating that a new ingredient can match or slightly outperform a traditional one. However, feeds are not formulated on a one-to-one basis. In practice, when a new ingredient is introduced, it does not simply replace another. Instead, the entire formulation shifts. Multiple ingredients are adjusted simultaneously to maintain nutrient balance, cost targets, and functional performance. This is how commercial least-cost

Table 1. SWOT analyses of players in feed formulations.

| | Academics | Ingredient companies | Feed mills | Consultants |
|---|---|---|---|---|
| **Strengths** | Focus on pushing boundaries, cutting-edge innovation. Strong integrity, ownership, and curiosity in research. Willingness to take risks and explore low-performing treatments. | Clear commercial interest ensures practical applications. Strong focus on validation and adding value to ingredients. Pushes ingredient inclusion rates to maximize performance. | Strong commercial focus ensures economic feasibility. Uses a co-ingredient replacement approach, considering overall feed value. Extensive engagement with digestibility studies. | Flexible approach, blending methodologies from academics, ingredient companies, and feed mills. Strong commercial focus ensures industry relevance. |
| **Weaknesses** | Lack of commercial interest, limiting direct industry application. Formulation approach primarily focused on single-ingredient assessment, which may not translate well to commercial feed formulations. | Conservative approach limits risk-taking and potential breakthroughs. May overemphasize product validation rather than broader nutritional strategies. | Conservative approach hinders rapid adoption of novel ingredients. Limited interest in fundamental research beyond commercial value. | Conservative approach may limit risk-taking and innovation. Potential for bias based on client needs rather than scientific objectivity. |
| **Opportunities** | Can lead fundamental discoveries that influence long-term industry advancements. Potential for collaboration with ingredient companies to validate innovations. | Can work with academics to validate novel ingredients. Potential to influence feed mills by demonstrating ingredient benefits. | Can use ingredient studies from academic and ingredient company research to screen potential winners and losers before second stage assessment internally. Opportunity to drive ingredient demand through practical applications. | Can bridge gaps between research and commercial application.Opportunity to guide formulation strategies based on multiple perspectives. |
| **Threats** | Misalignment with industry needs may reduce the impact of research.Lack of immediate commercial viability can limit funding and adoption. | High inclusion rates may not always align with feed formulation realities. Dependence on benchmarking against existing industry standards may limit innovation. | Dependence on established formulations may reduce adaptability to emerging innovations.Pressure for cost-effectiveness may limit investment in novel feed components. | Reliant on client demands, which may restrict independent innovation. Risk of favoring short-term commercial gains over long-term advancements. |

formulation works. Nutritionists define nutrient specifications and then optimize across a pool of ingredients, each with inclusion limits and constraints. The outcome is always a compromise between nutrition, economics, and increasingly, sustainability.

The idea that a single ingredient can "replace" another in isolation is, in most cases, a research construct rather than a commercial reality.

## Contextualizing single-ingredient studies

Single-ingredient studies are attractive because they are straightforward and provide clear cause-and-effect. They are also useful when investigating specific properties such as digestibility, palatability, or the presence of antinutritional factors. However, their limitations, particularly in terms of industry impact, are becoming more apparent. First, ingredients rarely match each other in terms of nutrition. Differences in compositions (e.g., amino acid profiles, energy content, and digestibility) make direct substitution nearly impossible. Small formulation adjustments, often limited to a few percentage points, are not enough to compensate for these differences. The result is often an imbalanced diet, which confounds interpretation. Second, these studies overlook the complexity of the feed matrix. Ingredients interact with synergistic or antagonistic effects that are not captured when evaluated in isolation. Finally, and most importantly, the translation of research outputs into industry outcomes might fall short.

## Co-inclusion is not new

The industry already uses co-inclusion strategies. Every commercial feed is based on combining multiple ingredients to achieve a balanced outcome. Co-inclusion, or co-ingredient formulation, shifts the emphasis from replacing individual ingredients to understanding how combinations of ingredients perform together. This approach allows formulations

to be balanced properly for digestible nutrients and energy. It also provides flexibility to manage ingredient variability and cost fluctuations. From a risk perspective, co-inclusion is inherently more robust. Relying heavily on a single ingredient increases vulnerability to supply disruptions and quality variation.

### Complexity in co-inclusion formulations

Co-inclusion studies are more complex to design and interpret. The effects are often more subtle, requiring deeper knowledge, stronger experimental designs and more sophisticated statistical approaches. Traditional statistical methods, such as simple comparisons with limited replication, may not be sufficient. Instead, there is a need for approaches that can capture interactions between ingredients, such as factorial designs, regression models, or simulation-based methods. Although it may entail greater cost and effort, generating outcomes that are practical requires embracing complexity rather than avoiding it.

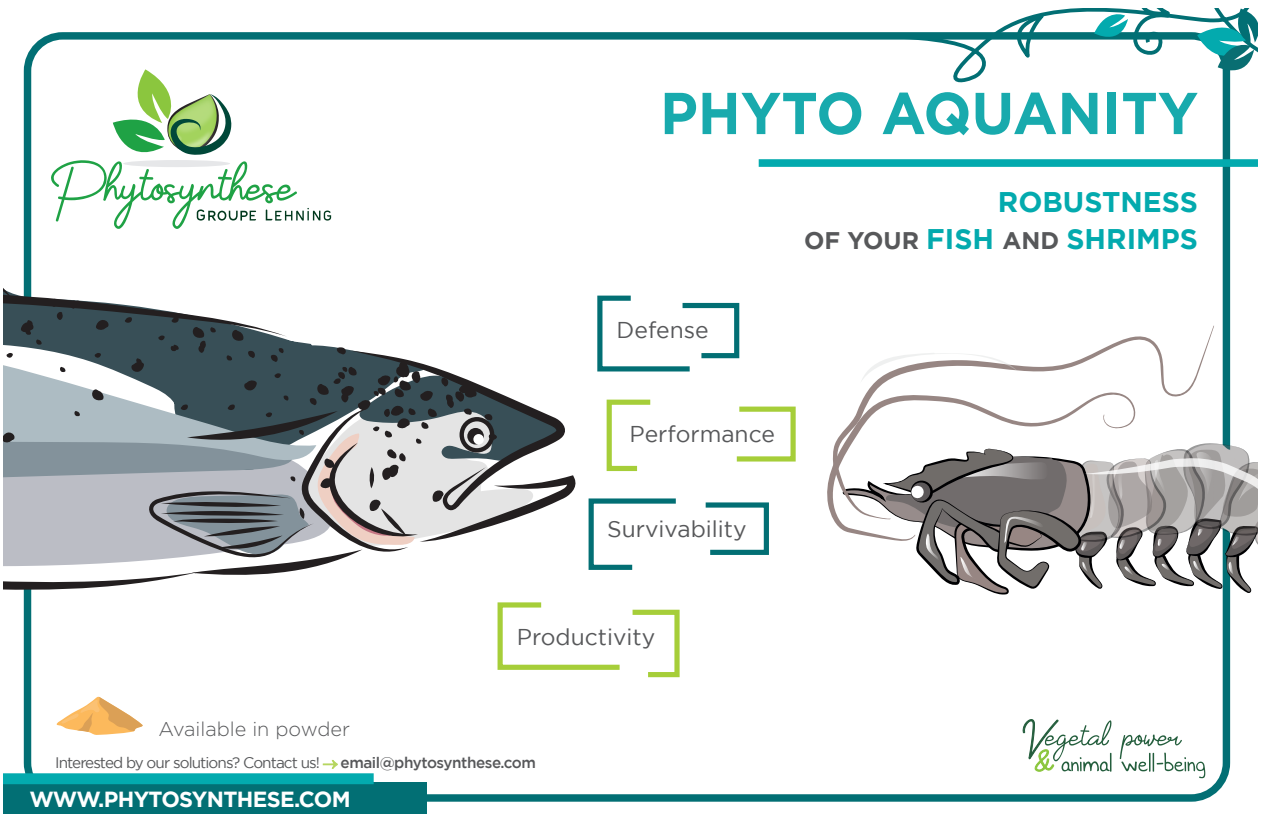
### Precision nutrition demands better data

The move towards co-inclusion also highlights the need for better ingredient characterization. Modern feed formulation is based on digestible nutrients and available energy. This requires detailed knowledge of ingredient composition, including batch-to-batch variability. It also requires an understanding of factors such as palatability, antinutritional compounds, and inclusion limits. These are often poorly defined or based on experience rather than data. Without this level of detail, it is more challenging to fully realize the benefits of co-inclusion strategies.

### Sustainability is forcing the shift

Environmental considerations are accelerating the need for more holistic formulation strategies.

Life cycle assessment has shown that ingredient selection involves trade-offs. An ingredient with a low carbon footprint may have higher impacts on land or water use. Focusing on a single metric can lead to unintended consequences. Co-inclusion provides a way to balance these trade-offs. By combining ingredients, it is possible to optimize across multiple environmental indicators rather than maximizing performance in just one. This is particularly relevant as sustainability frameworks and certification schemes become more influential. Feed formulations must increasingly



meet not only nutritional and economic targets, but also environmental and regulatory requirements. A narrow, single-ingredient perspective is not well suited to this reality.

### The social license to operate

Feed formulation is also influenced by social factors. Consumer perceptions, retailer requirements, and activist pressure all shape what is considered acceptable. Certain ingredients, including GM crops, animal by-products, and those linked to deforestation, can be contentious. Social media has amplified these debates, sometimes without a strong scientific basis. Co-inclusion strategies may increase exposure to these issues simply because they involve a broader range of ingredients. This makes transparency and communication more important than ever. The industry cannot rely on technical arguments alone. It must also engage with societal expectations and clearly communicate the rationale behind formulation decisions.

### Economics still matters most

At the end of the day, feed formulation is driven by economics. Co-inclusion strategies provide greater flexibility to respond to changing ingredient prices and availability. This is a major advantage in a volatile global market. They also reduce risk by avoiding over-reliance on specific ingredients. Single-ingredient studies, while useful for specific questions, often do not capture these economic realities. Their findings may be valid in a narrow context but difficult to apply at scale. In the context of delivering value and impact, it needs to reflect how feeds are actually formulated.

### Moving forward

This is not an argument to abandon single-ingredient research altogether. It still has an important role, particularly in understanding specific functional properties. However, it should not dominate the research landscape. There is a clear need to rebalance efforts towards more holistic approaches that reflect commercial practice. This includes:

- Designing experiments that consider multiple ingredients and their interactions
- Improving ingredient characterization, particularly for digestible nutrients and batch variability
- Incorporating sustainability metrics into formulation decisions
- Strengthening collaboration between researchers, feed manufacturers, and ingredient suppliers

Most importantly, it requires a shift in mindset, focusing on understanding how to use all available ingredients more effectively.

### A necessary shift

Aquaculture is entering a phase where efficiency, resilience, and sustainability are all critical.

Feed formulation sits at the center of these challenges. Continuing to rely on simplified, single-ingredient approaches risks slowing progress and limiting the impact of research. In contrast, embracing more holistic, co-inclusion strategies offers a pathway to more practical, flexible, and impactful solutions. The industry is already operating this way. It is time for research to leverage it.

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# Bridging innovation and scalability: Extrusion advances at Nofima

**Truls Wergeland**
Aquafeed Technology Centre, Nofima


The increasing use of novel and sustainable ingredients in aquafeeds is placing new demands on processing technologies. At the Aquafeed Technology Centre in Bergen, Norway, recent investments in advanced extrusion equipment are helping bridge the gap between ingredient innovation and commercial feed production.

The center, operated by Nofima, has installed a new high-tech extruder from Clextral, designed primarily to produce salmon feed, but also specialized feed for other farmed species, and bait for wild fish.

This upgrade comes at a time when Norway is intensifying its focus on sustainability, with a goal of using only sustainable ingredients in feeds and increasing the share of Norwegian raw materials from 8% to 25% by 2034. Achieving this goal requires extensive research and development, and feeding trials are an integral part of this.

The Aquafeed Technology Centre plays a key role in verifying if a novel ingredient can be successfully integrated into a commercial diet for farmed fish.

## Precision and control in feed production and pellet quality

In sharp contrast to the old extruder, which has been producing feed since 1989, the new extruder represents a significant technology leap. The new unit is fully automated and allows precise control of all production parameters through a digital interface.

Variables such as water and steam input, screw speeds and others can be modified with high precision. This level of control is particularly important when working with novel ingredients, which are often available in limited quantities. Minimizing raw material losses while optimizing processing conditions is therefore critical.

The technical quality of the feed and relevance to current fish farming conditions are of special importance.

Pellets must withstand high pressure during storage, transport, and feeding, while also ensuring optimal digestibility.

Key parameters such as pellet density and expansion must be carefully managed. Adequate expansion is necessary to allow oil coating, but excessive expansion can result in floating pellets, which are not suitable for all production systems.

In feeding trials, the only difference between treatments should be diet formulation; consistency of pellet quality is essential to avoid error in the trial. The recently-acquired advanced extrusion technology, combined with skilled operators, plays a crucial role in ensuring this level of control.

## Testing novel ingredients and specialized feeds

Since its installation in early 2025, the new extruder has produced approximately 60 tons of experimental feed, supporting a wide range of research projects. While some minor technical challenges have been encountered, overall performance has been positive.

One of the first feeds produced involved salmon feed with different inclusions of dried diatom algae, supplied by Finnfjord AS, a Norwegian ferrosilicon producer that cultivates the algae using $CO_2$ emissions from its power plant. The algae were dried in a spray dryer at the center, incorporated into a meal mix at different concentrations (0%, 5%, 10%, and 15%) and extruded. Despite lower starch levels at higher inclusions, good pellet quality was achieved. Feeding trials indicated that Atlantic salmon performed as well on diets containing up to 15% algae as on commercial diets. There were also indications of reduced lice levels with higher algae inclusion.

Algae have also been tested in other feeds, showing dried algae are well-suited as an ingredient when it comes to pellet quality. However, digestibility remains species-dependent. Due to the structure of algal cell walls, autotrophic algae are generally less digestible to fish than heterotrophic sources, making pre-treatment necessary to break the cell wall before mixing into a diet (Sørensen *et al*., 2023).

The utilization of poultry by-products in salmon feed has been gaining attention in recent years. As part of an ongoing project funded by the Norwegian Seafood Research Fund (FHF), diets containing up to 30% poultry meal were produced for digestibility trials, along with formulations fully replacing fishmeal for a growth trial. Results showed that pellets with high inclusion levels of poultry meal maintained good technical quality, supporting its potential as an alternative protein source. Biological performance results will be released soon.

Extrusion flexibility also enables the development of highly specialized feeds. For example, test feeds were produced for king crab fattening, targeting undersized individuals that would otherwise be discarded. King crab fishermen have, over the years, been challenged with parts of their catch being below the minimum size. However, these individuals can be transferred to tanks and fed until they reach the optimal size for distribution.

Crab feeds require distinct characteristics, including specific ingredient compositions and a C-shaped pellet design. This shape improves crabs' feed intake and facilitates efficient drying. Initial batches have been delivered for testing, with results pending.

## Bridging innovation and commercialization

Over decades of operation, Nofima has accumulated extensive expertise in feed technology, with around 1,500 projects conducted since 1989. This experience underscores the importance of iterative testing in optimizing formulations and processing conditions.

Production challenges are constant, but they are also what make the work both exciting and rewarding. Thanks to advanced infrastructure and skilled personnel, both at Nofima and across the industry, the gap between novel ingredients and commercial feed is being significantly reduced, helping to support the achievement of national sustainability goals.

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# How multifunctional whole egg powder optimizes FCR and water quality in *L. vannamei* farming

**Alex DIANA**
Actipro

## Where profit leaks: Hydrostability, nutrient loss, and pond health

In the intensive world of whiteleg shrimp (*Litopenaeus vannamei*) farming, the margin for error is razor-thin. Feed accounts for upwards of 50-60% of total production costs, yet a significant portion of that investment never reaches the intended consumer, the shrimp.

Unlike many finfish species that feed rapidly at the surface or in the water column, shrimp are slow, benthic feeders. They use their maxillipeds to handle and manipulate feed pellets, often for extended periods. This feeding behavior exposes a critical vulnerability in aquafeed formulation: hydrostability. When a pellet lacks structural integrity or a cohesive internal matrix, it begins to disintegrate and "leach" soluble nutrients, such as amino acids, vitamins, and minerals, into the water column within minutes of immersion.

This creates a double-edged sword for the farmer. First, it represents a direct economic loss due to the waste of high-value nutrients. Second, these leached nutrients fuel the proliferation of algae and pathogens, degrading water quality and increasing the pond's biological oxygen demand (BOD). To address this, formulators are increasingly looking beyond traditional binders. The industry requires a multifunctional solution that serves as both a nutritional powerhouse and a technical stabilizer.

## Whole egg powder for stronger pellets and smarter nutrition

Within ACTIPRO, we have pioneered the application of high-quality egg powder as a "technical-commercial" bridge in aquafeed. Unlike traditional binders or low-quality protein fillers, egg powder is a complex biological ingredient. It is produced through a gentle spray-drying process that preserves the functional properties of the proteins and lipids. In shrimp diets, egg powder serves a dual purpose. From a nutritional standpoint, it offers a complete amino acid profile with near-perfect bioavailability and, crucially, a natural source of cholesterol and phospholipids, nutrients essential for shrimp molting and growth but expensive to supplement in purified form. From a technical standpoint, its unique gelling, emulsifying, and binding properties create a pellet that is resilient to the mechanical stress of underwater handling.

The efficacy of egg powder in shrimp feed is rooted in the molecular behavior of egg proteins, which, when subjected to the heat and pressure of extrusion or pelleting, undergo changes and subsequent cross-linking. This creates a thermally irreversible three-dimensional protein network that locks other dietary components in place.

Furthermore, the natural phospholipids found in egg yolk function as a potent emulsifier. In formulations with high lipid content, lecithin ensures that fats are finely dispersed throughout the pellet matrix rather than pooling on the surface. This not only improves the "oil-holding capacity" of the feed but also creates a more hydrophobic barrier, further slowing the entrance of water and the subsequent leaching of water-soluble nutrients.

## Proof in the water: Testing shows up to 93% better retention

To quantify these benefits, we have conducted an internal study focusing on the retention of nutrients in *L. vannamei* diets. The research utilized water conductivity testing – a highly sensitive proxy for measuring the release of ionic and soluble solids from feed into the environment.

In this test, control diets (standard commercial formulations) were compared against diets fortified with ACTIPRO egg powder. The results were definitive: diets containing egg powder demonstrated up to a 93% improvement in nutrient retention compared to the control.

This data indicates that the egg powder-fortified pellets were 3.5 times more stable over a one-hour immersion period. By maintaining the integrity of the pellet matrix, the "fines" (micro-particles that break off and cloud the water) were significantly reduced. For the nutritionist, this means the calculated nutritional profile of the diet actually reaches the shrimp's midgut, rather than fertilizing the pond's microbial community.

## From lab to pond: Better FCR, cleaner water, and a circular-economy edge

The transition from "technical benefit" to "commercial success" in aquaculture is measured by three key metrics: Feed Conversion Ratio (FCR), water quality management, and growth rates.

- *Optimized FCR:* When nutrients are retained within the pellet, shrimp receive the full caloric and complete value of the feed. This leads to lower FCRs, as less total feed is required to achieve the same biomass gain. In an era of volatile commodity prices, even a 0.1 reduction in FCR can represent the difference between profit and loss.
- *Reduced environmental pressure:* By minimizing the leaching of nitrogen and phosphorus, egg powder helps maintain a stable pond ecosystem. This reduces

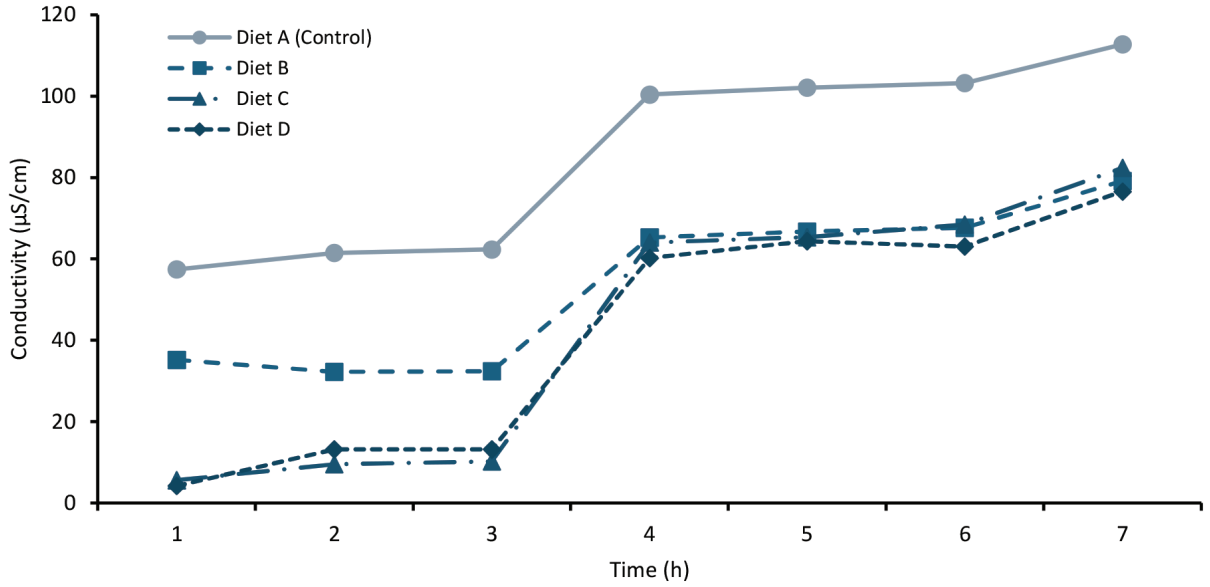


Figure 1. Conductivity over time for four different diets: Diet A is the control and does not include egg powder. Diet B contains 2% egg powder and Diets C and D contain 4% egg powder with different formulations.

the need for frequent water exchanges and chemical treatments, lowering operational costs and mitigating the risk of stress-induced diseases like Vibriosis.

- *The cholesterol advantage:* Since shrimp cannot synthesize cholesterol de novo, they must obtain it from their diet. Traditional sources, like fish oil or purified cholesterol, are costly and often unsustainable. Egg powder provides a bioavailable, "natural-package" source of sterols, supporting faster molting cycles and improved survival rates without the premium price tag of synthetic additives.

As the global aquaculture industry moves toward "Blue Transformation", the pressure to source sustainable, high-performance ingredients has never been higher. ACTIPRO's egg powder represents the pinnacle of circular economy principles, upcycling high-value co-products from the food industry into a strategic ingredient for shrimp feed producers and farmers.

By combining superior nutritional bioavailability with a 93% improvement in nutrient retention, egg powder is no longer just an "alternative protein." It is a technical improvement for the modern feed mill. For managers looking to enhance pellet durability, improve water quality, and maximize ROI, the choice is clear: the most efficient way to feed a shrimp is to ensure the feed stays in the pellet until it is eaten.

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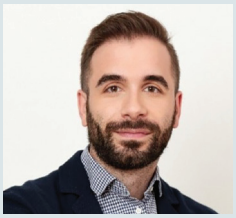

# Feed mixing: The heart of efficient aquaculture production

**Dejan D. Miladinovic**
Center for Feed Technology, Norwegian University of Life Sciences

Whether you're formulating diets for poultry, cattle, swine, or aquaculture, the goal is always the same: achieve a uniform blend of ingredients, so every animal receives the intended nutrients in every bite. Modern feed mills rely on mechanical mixers designed to handle a wide range of ingredients, from fine powders and minerals to fibrous materials and liquids. A variety of mixer designs exist, each with its own strengths and limitations. The most common types include ribbon mixers, paddle mixers, single shaft mixers, and twin shaft mixers. Understanding how each one works helps you choose the right equipment for your production scale, ingredient characteristics, and mixing precision requirements.

## Pros and cons of various mixing technologies

Ribbon mixers use helical ribbons mounted on a horizontal shaft to move material in opposing directions, creating a continuous mixing action. Those mixers are efficient for free-flowing powders and dry ingredients. Generally, ribbon mixers are less expensive than other mixer types and are suitable for large batch sizes. A simple design makes maintenance relatively easy. However, ribbon mixers are also not ideal for fibrous or sticky materials, or for batches that include a high percentage of wet ingredients or liquid additions. Longer mixing time compared to high-intensity mixers makes them less efficient. The high coefficient of variation (CV%) indicates that these mixers are at high risk of ingredient segregation during discharge if not well designed.

Paddle mixers use paddles mounted on a shaft to lift, fold, and tumble material, creating a gentle but thorough mixing action. They are excellent for ingredients that require fast handling and better-suited liquid addition compared to ribbon mixers. Paddle

mixers can handle a wide range of feed ingredients, including fibrous materials and wet ingredients. On the other hand, ribbon mixers have higher energy consumption than paddle mixers. More complex internal geometry can increase maintenance needs. Sometimes, paddle mixers may not achieve the same level of uniformity with very fine powders.

Among ribbon and paddle mixers, there are several types of shafts: single shaft mixers and twin shaft mixers. Single-shaft mixers (ribbon or paddle style) rely on a single central shaft to move material through the mixing chamber. Such a mechanical design is simpler than a twin-shaft; however, it is less expensive and easier to maintain. Single-shaft mixers are suitable for a wide range of feed types and they may be a good choice for small to medium-scale operations. However, the mixing intensity of single-shaft machines is limited than that of twin-shaft designs and requires a longer mixing time. Also, single-shaft mixers are less efficient for high-moisture or sticky formulations.

On the contrary, twin shaft mixers use two intermeshing shafts, often with paddles, to create a fluidized mixing zone where ingredients are suspended and rapidly blended. Those mixers have a faster mixing time. When compared to twin-shaft paddle mixers with twin-shaft ribbon mixers, the paddle mixers were found to be more efficient and produced better uniformity in a shorter time. Twin-shaft paddle mixers produce highly uniform blends, even with microingredients. Normally, the twin-shaft mixers, and especially paddle mixers, have higher initial investments. The twin-shaft paddle mixers are well-suited for liquid addition, including oils, enzymes, and molasses, in high-capacity industrial feed mills. However, even the best mixers offered to the feed manufacturers have their limitations. More complex designs increase maintenance requirements, and they may be excessive for small-scale operations.

## A new era in feed mixing

The Norwegian University of Life Sciences (NMBU) and its Center for Feed Technology (FôrTek) have introduced a breakthrough technology in feed mixing, the IsDeCa® batch mixer. Developed at the Center for Feed Technology (FôrTek), this mixer represents a major leap forward in handling high-liquid-content formulations, enabling feed producers to incorporate over 30% liquid ingredients, something traditional mixers, even twin-shaft paddle mixers, struggle with.

This innovation is designed to support modern feed challenges, including sustainable aquafeeds, circular raw materials, and high-fat or high-protein liquid inclusions. IsDeCa® uses a patented mixing principle that creates a highly efficient mixing environment capable of suspending and distributing large volumes of liquid ingredients without clumping or uneven coating. It competes directly with single-shaft and twin-shaft mixers while offering lower operational costs and improved performance.

The advantage of the IsDeCa® batch mixing technology is that it can handle liquid inclusions ranging from 1 to 50% (fats, proteins, marine byproducts) without compromising uniformity or overall mixing performance. The most important fact is that it is 30% cheaper than twin-shaft paddle mixers in comparable applications. The CV% achievable with IsDeCa® mixers can be even lower than 2.5% in ideal situations, indicating excellent mixing uniformity (Figure 1) and outperforming twin-shaft paddle mixers (Figure 2).

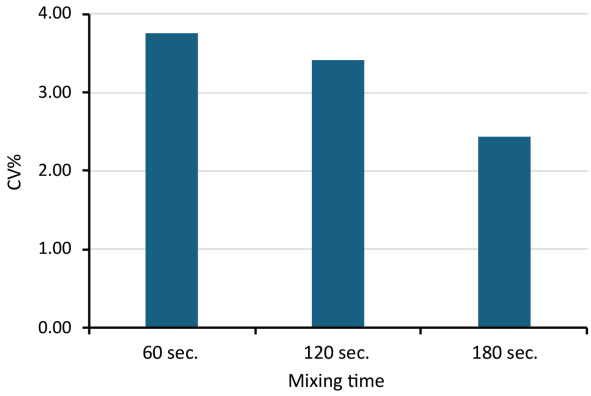


Figure 1. CV% of mixture containing $TiO_2$ and 1mm hammermilled soybean meal mixed in IsDeCa® 1000 lit. batch mixer. Source: Norwegian University of Life Sciences, Center for Feed Technology

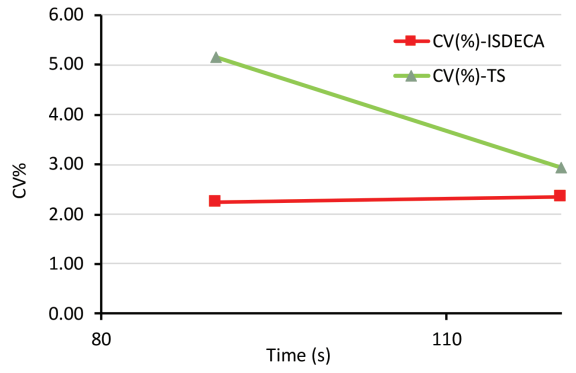


Figure 2. CV% analyses comparing 60 lit. twin-shaft paddle batch mixer and 60 lit. IsDeCa® batch mixer. $YttO_2$ was used as a marker and mixed with 1 mm hammermilled soybean meal for 90 and 120 seconds.

Table 1. Comparison of operational performance between commercial mixer types and IsDeCa®

| Category | Ribbon | Single-shaft paddle | Twin-shaft paddle | IsDeCa® |
|---|---|---|---|---|
| High liquid handling | 3 | 5 | 7 | 10 |
| Cost efficiency | 7 | 6 | 4 | 9 |
| Mixing uniformity | 6 | 7 | 9 | 10 |
| ***Overall Performance*** | ***5.3*** | ***6.0*** | ***6.7*** | ***9.7*** |

With its patented functionality and performance, IsDeCa® mixing supports sustainable feed production, enabling reduced reliance on traditional feed ingredients and increased use of circular raw materials. The IsDeCa® mixing technology is designed for both lab-scale and industrial-scale environments. Mathematical models tested by the Simula Research Laboratory, from 2.5 liters to 5,000 liters, showed the same mixing dynamics. Moreover, IsDeCa® is recently licensed for large-scale commercialization, ensuring industry adoption.

The cons of the IsDeCa® technology are that the new technology means limited long-term field data compared to decades-old mixer designs. Of course, such technology may require operator training due to its novel mixing principle. Integration into existing feed mills may require retrofit adjustments. Also, availability may be limited during early commercialization phases.

A comparison of operational performance between common mixer types and IsDeCa® is presented in Table 1. The scale (1–10) reflects relative performance based on reported capabilities, cost efficiency, and mixing uniformity. The overall performance ratings presented in the comparison chart reflect the author's own observations and interpretations based on available information about common mixer technologies and the reported capabilities of the IsDeCa® system. A direct, controlled comparative study between IsDeCa® and traditional mixers, such as ribbon mixers and single shaft paddle mixers, has not been conducted. Therefore, the values shown should be understood as indicative opinions, not as results from standardized experimental testing.

## Conclusion

Feed mixing remains one of the most decisive steps in modern livestock and aquaculture nutrition, shaping not only feed quality but also production efficiency, animal performance, and economic sustainability. As this overview shows, the industry has long relied on a spectrum of mechanical mixers, each engineered with distinct advantages and inherent limitations. Ribbon mixers offer simplicity and affordability but struggle with liquids and sticky materials. Paddle mixers offer greater versatility but require more energy and maintenance. Single shaft paddle systems deliver cost-effective reliability, while twin shaft paddle mixers set the benchmark for speed and uniformity, although at a higher investment cost.

Against this backdrop, the emergence of the IsDeCa® mixing technology marks a noteworthy shift in what feed manufacturers can expect from mixing equipment. Developed at the Norwegian University of Life Sciences, IsDeCa® introduces a patented mixing principle capable of handling exceptionally high liquid inclusions, up to 50%, while maintaining low CV% values and competitive operational costs. Its ability to suspend and distribute liquids efficiently positions it as a promising tool for the growing demand for sustainable, high-moisture, and circular feed ingredients. As feed production evolves toward more complex formulations and sustainability-driven ingredient strategies, mixing technology must keep pace. IsDeCa® represents a bold step in that direction, an innovation that challenges long-standing assumptions about what a mixer can handle and how efficiently it can perform. Whether it becomes a new industry standard will depend on continued research, field validation, and the willingness of feed manufacturers to embrace a new generation of mixing solutions.

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# Twin-screw extrusion: An innovative technology serving aquaculture feed production

**Hadrien Delemazure**
Clextral

The global aquafeed market is experiencing sustained growth, driven by the ongoing rise in demand for aquaculture products and the need to improve the efficiency of fish and crustacean feeding systems (Bouvier & Campanella, 2014).

The most recent study from the Food and Agriculture Organization of the United Nations (FAO, 2024) confirms that, for the first time, aquaculture surpassed capture fisheries in aquatic animal production, accounting for 57 percent of the production destined for human consumption.

| | |
|---|---|
| **Throughputs** | From 20 to over 34,000 kg/h (finished products) |
| **Equipment range** | From R&D systems to large-capacity industrial extruders |
| **Product sizes** | From micro-pellets (Ø 0.5 mm) to macro-pellets (Ø 30 mm) |
| **Pellet properties** | From floating (350 g/l) to fast-sinking (750 g/l) |

## Clextral designs high-performance twin-screw extrusion systems for aquafeed production

Clextral twin-screw extrusion lines enable the production of high-quality, energy-dense feeds, offering a precise balance of proteins, fats, and carbohydrates. They are particularly well-suited for processing raw materials and creating a wide variety of formulations. These feeds are engineered to improve digestibility while reducing waste.

Clextral twin-screw extruders precisely control pellet density according to the desired product characteristics, such as sinking behavior in water and buoyancy. A wide range of feeds can be produced to meet the nutritional requirements of each species and its stage of development, with perfectly calibrated products ranging from 0.5 to 30.0 mm.

By meeting the most demanding environmental and quality standards, twin-screw extrusion technology also helps maintain optimal water quality for healthy fish and improved feed conversion ratios with reduced losses.

Extruded pellets offer major nutritional and functional advantages, such as enhanced digestibility and pellet hardness. To meet this growing demand, Clextral designs sophisticated, automated complete extrusion lines capable of handling high-lipid formulations and incorporating alternative proteins, such as those derived from insects or microorganisms, within a sustainability-focused approach.

***FUNCTIONAL NUTRITION AND HIGH VALUE***

*PHASED FORMULATIONS (STARTER, GROWER, FINISHER) IMPROVE MARGINS BY ENHANCING BIOLOGICAL PERFORMANCE.*

***IMPLICATION: FLEXIBLE LINES CAPABLE OF HANDLING SENSITIVE ADDITIVES.***

## Energy efficiency: A critical challenge

Clextral develops highly efficient twin-screw extruders integrated with automated control systems to optimize energy efficiency and reduce operating costs.

"The aquafeed extrusion market lies at the intersection of quantitative growth – driven by the expansion of aquaculture product consumption – and qualitative transformation – supported by technological innovation, sustainability, and process optimization," said Hadrien Delemazure, Process Engineer – Feed Market Manager.

## Sustainability and new ingredients

For several years, the industry has been shifting toward plant-based, insect, and microbial proteins to reduce dependence on fishmeal. Clextral is developing innovations that provide even more possibilities for the aquaculture industry to process more complex materials with original formulations and to use raw materials such as new legumes, proteins, insects, krill meal, potentially processed animal proteins, algae, and more, while maintaining a strong focus on pellet quality and water stability.

## State-of-the-art industrial equipment – preconditioning: Increased efficiency and improved product texture

Another Clextral innovation concerns the preconditioning process, a key operation in fish feed manufacturing. Preconditioning enables humidification of the powder blend and pre-gelatinization of starch by adding water and steam, thereby improving pellet quality, increasing production capacity, and reducing extruder wear.

The patented, innovative preconditioner Pre-conditioner+ improves heat and mass transfer to the product through the Advanced Filling Control (AFC) device. It interacts directly with the material inside the mixing chamber and allows the filling rate to be adjusted. The AFC system uses a proprietary conveying screw inside the vessel and regulates flow through partial, controlled recycling of the processed material, thereby intensifying the preconditioning function.

Laboratory tests have shown that the final hardness of fish feed pellets increased by 7% to 29% using the same formulation while simply adjusting the preconditioner bottom screw speed.

During the cleaning procedure, the rotation of the bottom screw is reversed to facilitate cleaning of the preconditioning chamber.

## Hygienic industrial design

Today, significant attention is given to the hygienic design of extruders, as food safety is a key parameter for the fish feed industry and the food industry in general. Manufacturers want to be able to clean their extruders externally with hot water and sometimes with cleaning agents.

The hygienic stainless-steel Evolum+ frame is designed to prevent water stagnation, and all areas of the extruder are easily accessible. The internal twin-screw assembly must also be easy to clean. The complete quick barrel opening now represents a revolution in the industry: it allows access to the screws and barrels in just a few minutes and provides a cutting-edge solution that simplifies preventive maintenance, wear monitoring, and cleaning processes.

## Density control system

The density of aquaculture feed pellets must be adapted to the fish species' behavior to increase the likelihood of ingestion. Clextral has developed a system that allows the material density inside the extruder to be varied. Depending on the formulation, it is possible to quickly switch from an extruded pellet of 350 g/L to 750 g/L. This fully automated tool ensures pellet density control and enables the production of floating or sinking feeds.

The key advantages are:

- Precise density adjustment and control
- Production of high- or low-density products

Today, more and more aquafeed plants have already adopted this type of technology, signaling an accelerated modernization of production infrastructure on a global scale.

- Fines recovery system routed back to the preconditioner
- Ideal for aquaculture feed production

### Quick Change Die (QCD) system

The QCD system enables rapid switching between two product formats. Its purpose is to simplify extrusion die replacement by keeping a second die ready to mount on the extruder. This system reduces downtime and increases line productivity.

### Conclusion

The major challenge is to expand sustainable aquaculture to enhance food safety and economic development for the global population. In this context, extrusion technology has its role to play. The twin-screw extrusion technology contributes and will carry on with the changes, both in terms of nutritional value and in terms of physical quality characteristics of the aquafeed, with benefits for the fish, the feed mill, the farmer, and the environment.

*References available on request.*

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# Engineering the recipe for sustainable aquaculture

**Gunnar Hallmann**
Andritz

While the world's appetite for animal protein is at an all-time high, wild fish stocks remain stubbornly finite. The maths is straightforward, if somewhat inconvenient: relying on wild catch alone, there simply isn't enough fish to feed the world's growing population. While this reality has enabled steady expansion in fish farming – particularly across Africa, Southeast Asia, and the Middle East – it also invites criticism of sustainability that warrants a more nuanced response than it typically receives.

## The sustainability paradox

Critics often argue that aquaculture isn't sustainable because farmed fish are still fed fishmeal and fish oil derived from wild catch. It's a fair challenge on the surface, but one that only tells half the story.

The reality is that well-managed aquaculture, when supported by modern feed technology, is one of the most efficient ways to produce high-quality protein. Farmed fish are among the most efficient converters of feed into high-quality protein and with a considerably lighter environmental footprint. Without fish farming, global demand would simply shift to other protein sources. The most likely alternative is more land-based meat production – pork, beef, chicken – which directly translates to more methane emissions, more land use, and higher water consumption. Suddenly, aquaculture starts to look considerably more sustainable.

The story doesn’t stop there. In Northern European salmon farming, feed formulations have undergone a quiet revolution. Thirty years ago, salmon diets comprised around 70% fishmeal and fish oil. Today, that

share has dropped to roughly 15%, with the balance replaced by carefully selected vegetable proteins and oils. This shift didn't happen by accident; it's a result of constant innovation. But while more sustainable formulations continue to evolve, the engineering challenge moves with them.

## The processing challenge

The shift from fish-based to plant-based ingredients fundamentally changes how raw materials behave during processing.

Advanced extrusion and drying systems must now accommodate formulations that would have been unthinkable a generation ago. Plant proteins don't bind quite the same way as fishmeal, and vegetable oils have different thermal properties than fish oils. Yet the end product – whether floating pellets for salmon or tilapia, or high-durability sinking pellets for shrimp – must still hit the same benchmarks for water stability, nutrient retention, digestibility, and feed conversion performance.

Water stability deserves special attention. A pellet that disintegrates prematurely wastes expensive ingredients, leaches excess nutrients into the water column, and boosts feed conversion ratios – undermining the very environmental credentials aquaculture producers work hard to establish.

Modern processing equipment must therefore create pellets robust enough to withstand handling and keep their structural integrity in water, all while working with ingredient profiles that continue to evolve. Achieving this stability depends on factors such as extruder energy input, die design, and carefully controlled residence time in the dryer — all of which must be tuned to the formulation.

## Rising to the challenge

This is where processing expertise becomes decisive. Reformulating a diet is one thing, but ensuring your processing line can handle that reformulation without compromising pellet quality is another thing entirely.

Aquafeed production is a chain of interdependent steps, from grinding and mixing through to extrusion, drying, and cooling. Optimize one step in isolation, and you risk creating problems downstream. Each process is connected, which means the entire line needs to be considered as a system rather than a collection of individual machines.

This is the case for complete-plant expertise. Suppliers who can engineer and coordinate the full processing line, rather than supplying isolated pieces of equipment, are better positioned to tune each stage for evolving formulations. This allows each step to work in tandem and deliver integrated aquafeed processing lines. So when a formulation changes, the implications can be traced and adjusted across the whole system rather than being troubleshot piecemeal.

This interconnected approach matters, especially for emerging aquaculture markets where local engineering ecosystems are still maturing and operators may not have the in-house expertise to manage multiple specialist suppliers at the same time. In these environments, a single experienced partner, such as ANDRITZ, that understands the full process, adds significant practical value.

Understanding how formulation changes ripple through an entire production line is crucial. Especially as aquafeed recipes continue to evolve, that knowledge will be the difference between a pellet that performs and one that doesn't.

## Looking forward

The aquafeed industry stands at an interesting intersection. Demand will continue to grow as the global population increases and people recognize that fish farming is essential to global food security. Sustainability expectations are rising, pushing formulations toward lower fishmeal inclusion and higher plant-based content. Processing technology needs to keep pace, handling tomorrow's formulations without sacrificing the pellet quality that makes aquaculture operations viable.

The aquafeed manufacturers that thrive will always be prepared for what's coming next: complex formulations, evolving ingredients, exacting sustainability standards, and an industry that can't afford to stand still. Without this forward thinking, there simply wouldn't be enough fish to go around.

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# The vannamei revolution in Bangladesh: A strategic briefing on the nutritional imperative and market opportunity

**Mahbub Alam Khan (Shahin)**
Solution of Fisheries & Aquaculture

The commercial introduction of Pacific white shrimp (*Litopenaeus vannamei*) in Bangladesh, particularly across the Khulna, Satkhira, and Bagerhat regions, represents a critical, high-return intervention needed to revitalize the nation's stagnant shrimp export sector. Pilot trials have confirmed strong yield potential, achieving 5.0 to 8.9 MT/ha in shot production cycles, compared to the economically uncompetitive 0.35 MT/ha/year typical of traditional *Penaeus monodon* farming.

However, the projected stakeholder demand of 100 crore post larvae (PL) for the upcoming season has exposed a serious nutritional and supply chain challenge. The estimated requirement for high-quality, species-specific feed is approximately 350,000 metric tons (3.5 Lakh MT). The continued reliance on local, low-protein feed (20-28% crude protein, CP) is scientifically incompatible with vannamei's needs (35-44% CP), significantly limiting profitability and jeopardizing the industry's success. Immediate investment in domestic SPF hatchery capacity and mandatory, quality-controlled feed production is paramount.

This briefing provides a comprehensive analysis of the market opportunity, identifies the key bottlenecks in feed and seed supply, and offers targeted, practical recommendations for business owners, government bodies, and farmers to ensure the sustainable and profitable growth of this emerging industry.

## Current situation and context

### *State of the traditional shrimp industry*

The traditional shrimp industry in Bangladesh, historically dominated by the black tiger shrimp (*P. monodon*), is at a crossroads. It faces multiple challenges, including low productivity, widespread white spot disease (WSSV), and declining export earnings. Bangladesh's current yield (0.0347 tonnes/ha) is about seven times lower than the global average and twelve times lower than that of neighboring India. Export earnings dropped by 35% between 2014-2015 and 2020-2021.

***The vannamei transition***

*L. vannamei* was introduced on a pilot basis in 2019, with the government of Bangladesh officially approving its commercial cultivation in March 2023. For the country's shrimp sector, the transition from monodon to vannamei is not just strategic; it is essential for economic survival. The global market has already set the standard, and to remain competitive, Bangladesh must adopt the species that defines modern aquaculture efficiency and scale.

For years, the sector has been constrained by the low productivity and disease susceptibility of black tiger shrimp. In contrast, the proven performance of *L. vannamei* offers a clear path to restoring competitiveness. Performance metrics (Table 1) highlight the species' advantages, including higher yield potential and shorter production cycles, which have already transformed the global shrimp industry.

***Current PL and feed dependency***

The initial pilot phase involved stocking an estimated 2-5 crore PL. Notably, approximately 80-90% of the stocked PL was imported, mainly from India, with only one domestic source supplying around 1 crore PL. Furthermore, most local farmers currently rely on existing black tiger (*Bagda*) shrimp feed, which is unsuitable for vannamei.

## Potentiality and economic drivers

The projected 100 crore PL demand confirms strong market confidence, a major leap from the estimated 2-5 crore PL stocked in the current season's pilot projects. Based on a commercially competitive FCR of 1.3, this demand translates into a substantial requirement for approximately 350,000 metric tons (3.5 Lakh MT) of specialized high-protein feed for the coming year.

At present, local capacity for this specific feed formulation is negligible, creating a guaranteed market and a significant gap for business investment. Realizing this potential depends entirely on immediately addressing the critical challenges in feed and seed supply.

## The nutritional imperative: Requirements and deficiencies

Optimized nutrition is the primary driver of cost efficiency and success (FCR ≤1.3:1). Despite the sector's strong potential, it is constrained by two interconnected challenges: a major mismatch in feed quality and an unreliable, import-dependent seed supply chain. These issues pose immediate risks to farmer profitability, national production targets, and long-term industry sustainability.

***Detailed nutritional requirements***

The dietary needs of *L. vannamei* under intensive systems differ from those of *P. monodon*. The core issue is the widespread use of locally available *Bagda* (black tiger) shrimp feed, which is formulated for low-density, extensive systems. This makes it scientifically incompatible with the metabolic and growth requirements of intensively farmed *L. vannamei*. This mismatch leads directly to stunted growth, higher operational costs, and increased disease susceptibility.

***The critical feed composition mismatch***

The economic consequences of this feed mismatch are severe. Every 0.1-point increase in FCR above the 1.3:1 target is not just a statistic; it represents millions of taka in wasted feed and lost revenue, directly impacting farmers and the national economy.

Table 1. Competitive advantages of *L. vannamei* farming.

| Metric of competitiveness | Strategic advantage of *L. vannamei* |
|---|---|
| **Global market share** | *L. vannamei* dominates over 77-80% of the world's shrimp trade, creating a massive, established export market. |
| **Typical annual yield** | *P. monodon* yields are an uncompetitive 0.35-0.6 MT/ha/year. Pilot projects for *L. vannamei* have already achieved 5.0 to 8.9 MT/ha. |
| **Culture cycle duration** | *L. vannamei* reaches market size in a rapid 90-110 days, allowing for 2-3 crops per year from the same land area. |
| **Profitability** | Regional data shows net returns for *L. vannamei* (approx. 41,640) are significantly higher than for *P. monodon* (approx. 16,313). |

Table 2. Nutritional profile comparison of local and imported feed varieties vs. industry benchmark for intensive *P. vannamei* cultivation.

| Nutrient Parameter | Local *Bagda* feed (average) | Obonti Feed (Fishtech imported) | Optional benchmark | Impact on profitability |
|---|---|---|---|---|
| **Crude protein (CP%)** | Approx. 20-28% | Approx. 32% | 35-38% (optimized grower/finisher) | Stunted growth, compromised immune function, high mortality |
| **Essential amino acids** | Unoptimized; low lysine and methionine | Adequate | High specific density (crucial for FCR and growth) | |
| **Lipid content** | Variable | Adequate (3-6%) | 6-8% (focus on HUFA, DHA, EPA) | Weak energy supply |
| **Water stability** | Poor/low | Good | Excellent (2-4 hours minimum; critical for low water pollution) | Nutrient leaching, water pollution, and increased disease risk (e.g., vibriosis) |
| **Expected FCR** | ≥2.0:1 (inefficient) | Approx. 1.4:1 | ≤1.3:1 (target for cost-benefit) | High production cost, reduced profitability, and potential for financial insolvency |

It undermines the profitability that makes vannamei the superior choice, increasing the risk of farm failure and sector-wide stagnation.

***Effectiveness of soybean meal and mitigation strategies***

To reduce reliance on increasingly expensive and limited fishmeal, soybean meal (typically 44-48% CP) is a key plant-based protein source.

SBM is a cost-effective alternative to fishmeal and provides a strong amino acid balance, particularly lysine. Rahman et al. (2022) reported that vannamei can efficiently utilize locally produced feeds containing SBM and fishmeal substitutes, achieving favorable FCR values (1.2-1.5).

However, SBM has some limitations:

- Limiting amino acid: SBM is deficient in methionine, requiring supplementation with synthetic amino acids to balance the diet.
- Anti-nutritional factors (ANFs): Raw or under-processed SBM contains ANFs, such as trypsin inhibitors, lectins, and saponins, that reduce nutrient digestibility and may cause intestinal inflammation in shrimp.

Mitigation strategies include optimized inclusion levels at 10-25% for *L. vannamei*. Proper heat treatment, fermentation (FSBM), or the use of soy protein concentrate are necessary. Furthermore, incorporating exogenous digestive enzymes (e.g., proteases and phytases) is recommended to improve nutrient absorption and reduce environmental waste.

## Major problems and strategic mitigation measures

Despite key infrastructure, gaps must be addressed to manage risk and scale commercially.

***Seasonal (cold stress) nutritional mitigation***

*L. vannamei* is a tropical species with an optimal temperature range of 28-30 °C. Low temperatures (below 24 °C) decrease feed intake and suppress digestive enzyme activity.

To address cold stress, diet quality must be enhanced rather than reduced. The strategy should be holistic, focusing on digestibility, nutrient quality, and health-promoting additives. Diets should contain high protein levels (40-45% CP) and highly digestible protein sources like processed soybean meal, with methionine deficiencies corrected through supplementation.

To build resilience, feeds should be fortified with functional additives such as probiotics (Bacillus spp.), immuno-stimulants (beta-glucans, MOS), and stabilized vitamins C and E. Feeding rates should be systematically reduced and carefully monitored using feeding trays to avoid overfeeding and nutrient waste.

These technical requirements form the foundation for the targeted, actionable recommendations needed to advance the sector.

## Prioritized recommendations for sustainable growth

Based on the nutritional requirements and projected market demand, the following actions should be prioritized:

***Recommendations for the aquaculture sector and government bodies (policy)***

- *Enforce mandatory feed standards (CRITICAL):* Immediately establish and enforce a high standard for *L. vannamei* feed quality (≥35% CP, high water stability) under the Fish Feed and Animal Feed Act, 2010. Prohibit the use of *Bagda* feed for vannamei.
- *Accelerate PL/broodstock development:* Provide financial incentives and fast-track licensing for SPF broodstock quarantine facilities and hatcheries to meet the domestic demand of 100 crore PL, reducing reliance on imports and improving biosecurity.
- *Strengthen biosecurity investment:* Expand incentives and streamline approvals for SPF broodstock and hatchery development to mitigate import dependency and reduce disease risks.
- *Water management training:* Launch donor-funded programs focused on intensive water management, including advanced aeration techniques, water treatment protocols, and disease monitoring systems.
- *Support infrastructure:* Facilitate concessional financing to help farmers upgrade existing ghers to intensive systems, including access to specialized aquaculture loans and shrimp crop insurance.

***Recommendations for business owners (feed millers & entrepreneurs)***

- *Invest in feed production capacity:* Allocate capital to establish new or retrofit existing feed mills to address the 350,000 MT market gap. Production should meet international standards (CP ≥38%).
- *Ensure nutritional precision:* Formulate feeds with balanced amino acid profiles, particularly methionine supplementation, and incorporate high-quality, digestible plant proteins such as soybean meal.
- *Secure ingredient supply chain:* Develop reliable sourcing channels for sustainable, high-quality protein ingredients (e.g., soybean meal and fishmeal alternatives) to meet the 35-38% CP requirement.
- *Technical collaboration:* Partner with international aquaculture nutrition experts to develop locally optimized feed formulations that achieve FCR ≤1.3:1.
- *Strengthen quality control:* Implement rigorous raw material testing and adopt modern extrusion technologies with high-quality binders to ensure pellet water stability (2-4 hours), which is critical for maintaining FCR efficiency and water quality.

***Recommendations for farmers (local and farm operators)***

- *Adopt high-protein feed (mandatory):* Discontinue the use of local *Bagda* feed immediately. Use only 35-38% CP feed certified for *L. vannamei*, and employ feeding trays to monitor consumption and optimize FCR.
- *Adopt modern technology:* Invest in aeration systems and routine water quality testing (DO, pH, alkalinity) to effectively manage intensive farming conditions.
- *Engage in training programs:* Participate in specialized training on vannamei farming, including biosecurity practices, water parameter management, and species-specific feeding strategies.

Table 3. Operational challenges and targeted mitigation strategies for intensive shrimp production in Bangladesh.

| Challenge | Impact on project feasibility | Mitigation strategy |
|---|---|---|
| **Seed supply & biosecurity** | High dependence on imported PL, which risks disease introduction (WSSV, AHPND) and supply chain instability. | Establish domestic SPF Hatcheries and quarantine facilities to produce local Specific Pathogen-Free (SPF) seed stock. |
| **Feed quality & supply** | Suboptimal local feed (≤32% CP, low EAA, inconsistent lipids) leads to high FCR, reduced margins and increased disease susceptibility. | Invest in specialized feed mills to produce high-protein (≥38% CP), nutrient-dense pellets with optimized amino acid and lipid (HUFA, DHA, EPA) profiles. |
| **Technical knowledge gap** | Lack of proficiency in intensive culture methods, advanced biosecurity, and precision water quality management. | Implement comprehensive capacity-building programs focused on aeration, biofloc, and PCR-based disease monitoring. Maintain strict adherence to optimal water ranges: DO >4.0 mg/L, pH 7.5-8.5, Alkalinity >80 mg/L, and TAN <2.0 mg/L to prevent toxicity and disease |
| **Financing & insurance** | Substantial CAPEX (approx. BDT 2 million/ha) combined with a lack of specialized credit or crop insurance elevates financial risk. | Launch specialized aquaculture loan schemes and tailored shrimp crop insurance products to de-risk investments. |

Credits: Shutterstock

- *Implement cluster-based farming:* Adopt coordinated, cluster-based farming systems to synchronize production cycles and strengthen shared biosecurity measures, reducing the risk of disease outbreaks.

## Conclusion

The rapid expansion of *Litopenaeus vannamei* aquaculture in Bangladesh presents a strategic opportunity to significantly enhance national shrimp production. However, continued growth is constrained by critical gaps in species-specific nutrition, biosecurity infrastructure, and domestic input supply.

The current 3.5 lakh MT feed deficit undermines production efficiency and increases FCR and susceptibility to disease outbreaks, especially in systems that still rely on traditional feeding practices and inadequate water quality management. To achieve sustainable intensification, the industry must adopt technology-driven, biosecure farming practices supported by high-quality functional feeds, SPF broodstock, improved diagnostics, and standardized management protocols.

This proposal addresses these foundational challenges by strengthening nutritional capacity, improving supply chain resilience, and establishing a science-based production framework. By closing these gaps, Bangladesh can fully realize the genetic potential of vannamei, reduce production losses, and position itself as a competitive and reliable supplier in the global shrimp market.

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# Industry Events

## 2026

### MAY

| | | |
|---|---|---|
| 12 – 13: | Future Fit Asia 2026 | futurefitasia.com |
| 12 – 13: | Aquaculture UK | aquacultureuk.com |
| 18 – 21: | XXII International Symposium on Fish Nutrition and Feeding (ISFNF) | isfnf.com |
| 19 – 21: | FEFAC Congress 2026 | fefac.eu |
| 27 – 28: | Blue Food Innovation Summit | bluefoodinnovation.com |
| 27 – 28: | 23nd Practical Short Course: Trends and Markets in Aquaculture Feed Ingredients, Nutrition, Formulation and Optimized Feed Production and Quality Management | smartshortcourses.com |

### JUNE

| | | |
|---|---|---|
| 2 – 4: | VIV Europe & VICTAM International, The Netherlands | www.viveurope.nl |
| 2 – 5: | World Aquaculture 2026, Singapore | www.was.org |
| 10 – 11: | IFFO China Summit | www.iffo. com |

### JULY

| | | |
|---|---|---|
| 6 – 10: | Practical Short Course on Extruded Pet Foods and Treats 2026 | www.web.cvent.com |

### SEPTEMBER

| | | |
|---|---|---|
| 1 – 3: | Global Shrimp Forum, The Netherlands | www.shrimp-forum.com |
| 7 – 8: | Mucosal Health in Aquaculture | www.irta.cat |
| 21 – 24: | Responsible Seafood Summit & TCRS Shrimp Summit, Thailand | www.globalseafood.org |
| 28 – 29: | 4th International Conference on Aquatic Animal Epidemiology (AquaEpi IV) | www.aquafeed.com |
| 28 – Oct 1: | Aquaculture Europe, Slovenia | www.aquaeas.eu |

### OCTOBER

| | | |
|---|---|---|
| 1 – 3: | AquaExpo, Ecuador | www.aquaexpo.com.ec |
| 27 – 28: | Latin American & Caribbean Aquaculture 2026 | www.was.org |

### NOVEMBER

| | | |
|---|---|---|
| 10 – 13: | EuroTier 2026, Germany | www.eurotier.com |

### DECEMBER

| | | |
|---|---|---|
| 1 – 4: | World Aquaculture 2026 Tanzania | www.was.org |

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