Food and Agriculture Organization of the United Nations

THE GROWTH OF SINGLE-CELL PROTEIN IN AQUAFEED

Proteins made from single-cell organisms are being produced in growing quantities for aquafeeds. Heralded by their proponents as a sustainable alternative to the use of fish meal, some studies also suggest that they can provide health benefits for a variety of farmed aquatic animals.

Fed aquaculture species, which constitute around 70 percent of aquatic animal production globally (Hua *et al.*, 2019), require higher protein content in their diets. This typically ranges from 35 percent to 60 percent, compared to 12 percent to 26 percent for terrestrial livestock. For carnivorous species, such as salmonids and shrimp, the bulk of this protein has been traditionally sourced from fish meal, due to its high levels of crude protein and essential amino acids.

Fish meal is largely made of ground, dried forage fish – generally small pelagic species such as the Peruvian anchovy (*Engraulis ringens*). Around 15 million tonnes of wild forage fish are caught each year, specifically for fish meal (4.5 million tonnes) and fish oil (1 million tonnes) production. Aquaculture utilizes 69 percent of the world's fish meal and 75 percent of the world's fish oil consumption and this is one of the major criticisms levelled at the sector.

Moreover, aquaculture competes with fish meal use in the diets of swine, poultry and pets, and fish meal production cannot match the growth of all of these industries without jeopardizing forage fish stocks. Although feed producers have managed to significantly reduce the levels of fish meal in their formulations, the continued growth of the sector means that a shortage of between 0.4 million tonnes to 1.32 million tonnes of fish meal is forecasted to occur by 2050 (Jones *et al.*, 2020).

While fish meal has been partially replaced with ingredients from the agriculture sector such as soy protein concentrate (SPC), this has also raised sustainability questions. For example, Brazilian soy cultivation has increased by 167 percent since the turn of the century and this growth is widely associated with deforestation of ecologically important areas such as the Amazon Basin. No matter where the soy industry expanded – if it expanded – it would put pressure on limited land, water and phosphorous fertilizer resources.

The increased inclusion of plant-based proteins has also raised questions relating to fish welfare – while SPC might have a similar protein content compared to fish meal, it does not have the same nutritional profile and it can cause enteritis in fish such as salmon. Moreover, plant-based protein sources such as soy can also contain antinutritional compounds, like phytic acid.

As a result of these factors, and due to the continued growth of the global aquaculture sector, the search for alternative sources of proteins is being stepped up. In the last decade, in particular, a number of companies have emerged in the alternative protein sector. These include producers of proteins from single-cell organisms such as bacteria, yeast and microalgae.

A facility capable of producing 20 000 tonnes of single-cell protein a year is currently under construction in China, in a joint venture between Adisseo and Calysta.

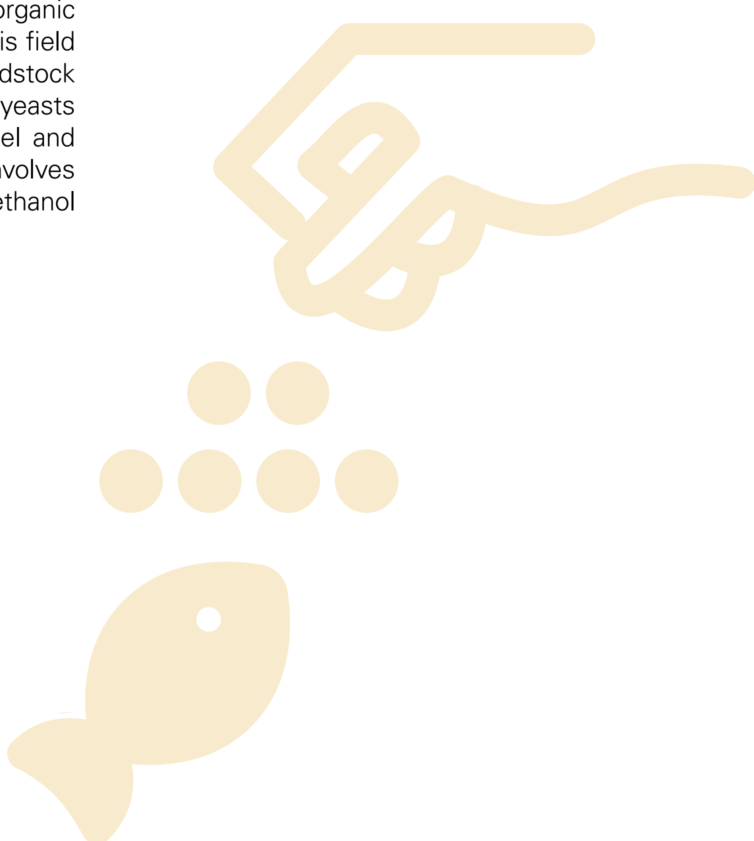
TECHNIQUE AND APPROACH USED

Although microalgae can be produced for their protein content, they are more commonly grown for their lipid levels, so this review will focus on yeasts and bacteria. Research into producing these organisms for animal feeds has been ongoing since the 1970s and many companies have emerged in the sector in the past decade.

In general, these organisms are fed using residues and by-products from other sectors, due to their comparatively low costs and sustainability credentials. Different companies have adopted different approaches to their production. The two key considerations relate to the species of organism that they are trying to produce and the source of feed material required.

Feedstock yeasts and bacteria include carbon dioxide, ethanol and brewery by-products and the single-cell organisms are produced in aerobic, anaerobic or gas bioreactors – depending on their needs (Glenncross, Huyben and Schrama, 2020). Feed sources currently being used include methane and carbon dioxide waste streams from refineries and power plants.

Heterotrophic organisms are produced using organic carbon as a feedstock and most companies in this field are focused on using waste or cellulosic feedstock such as dried distillers' grain or ethanol, while yeasts are produced using by-products from the biofuel and brewing industries. Another growing segment involves methylotrophs, which consume methane or methanol as a feedstock.



© Calysta

Single-cell protein is made from methylotrophic bacteria, which are fed on methane.

SCOPE AND SCALE OF APPLICATION

There are currently dozens of single-cell protein (SCP) producers who are looking to become involved in the aquafeed sector – with those in Asia, Europe and North America leading the field. Those relying on methane as a feedstock are currently the most advanced – with methanotrophic companies currently operating in locations including China, Denmark, India, the United Kingdom of Great Britain and Northern Ireland, and the United States of America.

In terms of the application of the end product, SCPs have been tested in the diets of a range of farmed aquatic species, including rainbow trout (*Oncorhynchus mykiss*), Atlantic salmon (*Salmo salar*) and whiteleg shrimp (*Penaeus vannamei*). Studies on one methanotroph have shown that it can make up to 52 percent of the protein required in the diets of Atlantic salmon and 38 percent of that required by rainbow trout with no adverse growth effects (Jones *et al*., 2020). A microbial protein was also tested in whiteleg shrimp diet (The Fish Site, 2017). It was shown to outperform the standard fishmeal-based feed.

ACCESSIBILITY

SCPs can be produced in a range of environments, using various technologies such as aerobic, anaerobic and gas bioreactors. While commercial-scale SCP production requires significant levels of investment, it is not limited by geography, as is reflected by the range of countries in which SCP-producing facilities are situated. The key requirement is to have access to suitable feedstocks – most of which are currently sourced from other industrial processes.

OUTCOME AND BENEFITS

SCP-based protein meals have the potential to provide the aquaculture industry with a sustainable, renewable feed ingredient, which can make up for the deficiencies of plant-based ingredients and reduce the need for fish meal in aquafeeds and terrestrial animal feeds.

Some studies have suggested that SCPs also have functional benefits that include enhancing disease resistance in species such as salmon, trout and shrimp. For example, recent laboratory-based trials suggest that an SCP derived from a methanotrophic bacterium can improve resistance to early mortality syndrome in whiteleg shrimp, although these trials have not yet been validated in the field (The Fish Site, 2021).

The use of SCPs instead of soy has also been shown to reduce enteritis in Atlantic salmon, suggesting another way that these ingredients can improve the health and welfare of farmed fish (Romarheim, 2011).

Another potential advantage of SCPs is their ability to convert environmentally harmful waste products into nutritional products. Methanotrophs, for example, convert methane – which has a global warming potential 25 times higher than that of carbon dioxide – into carbon dioxide and water (EPA, 2022).

Despite the promise of the sector, it still needs to scale up considerably to have a significant impact on global aquafeed formulation and to bring radical changes to the sector. Although SCPs are now being commercially produced by a number of companies, there are still challenges relating to the cost of production, the volume of production and the processing of the SCPs. A considerable reduction in price and increase in volume will be required before SCPs are widely used by aquafeed producers and aquatic farmers.

REFERENCES

EPA (The United States Environmental Protection Agency). 2022. Overview of Greenhouse Gases. In *EPA.* Washington, DC. Cited 20 April 2022. www.epa.gov/ghgemissions/overview-greenhouse-gases

Glenncross, B., Huyben, D. & Schrama, J.D. 2020. The application of single-cell ingredients in aquaculture feeds – a review. *Fishes,* 5(3): 22.

Hua, K., Cobcroft, J.M., Cole, A., Condon, K., Jerry, D.R., Mangott, A., Praeger, C., Vucko, M.J., Zeng, C., Zenger, K. & Strugnell, J.M. 2019. The future of aquatic protein: implications for protein sources in aquaculture diets. *One Earth,* 1(3): 316–329.

Jones, S.W., Karpol, A., Friedman, S., Maru, B.T. & Tracy, B.P. 2020. Recent advances in single cell protein use as a feed ingredient in aquaculture. *Current Opinion in Biotechnology,* 61: 189–197.

Romarheim, O.H., Øverland, M., Mydland, L.T., Skrede, A. & Landsverk, T. 2011. Bacteria grown on natural gas prevent soybean meal-induced enteritis in Atlantic salmon. *The Journal of Nutrition,* 141(1): 124–130.

The Fish Site. 2017. Shrimp thrive on fishmeal replacement. In: *The Fish Site.* Hatch Accelerator Holding Ltd, Cork, Ireland. Cited 20 April 2022. https://thefishsite.com/articles/shrimp-thrive-on-fishmeal-replacement

The Fish Site. 2021. A non-medicinal means for shrimp farmers to combat EMS/AHPND. In: *The Fish Site.* Hatch Accelerator Holding Ltd, Cork, Ireland. Cited 20 April 2022. https://thefishsite.com/articles/a-non-medicinal-means-for-shrimp-farmers-to-combat-ahpnd-ems-calysta-feedkind-thailand

ACKNOWLEDGEMENTS

This brief was prepared by Rob Fletcher (FAO consultant).

Required citation: FAO. 2022. *The growth of single-cell protein in aquafeed.* Bangkok.

FAO Regional Office for Asia and the Pacific
FAO-RAP@fao.org
www.fao.org/asiapacific/en/

Food and Agriculture Organization of the United Nations
Bangkok, Thailand