Chronicle of Aquatic Science

TYPE: Mini-review
PUBLISHED: 27 July 2023
ISSUE: Volume 1, Issue 2
ARTICLE ID: CoAS_V1IS2_02

OPEN ACCESS

EDITED BY
Ankures Bhattacharya
West Bengal University of Animal and Fishery Sciences

REVIEWED BY
Dr. Surya Kanta Sau
West Bengal University of Animal and Fishery Sciences

Dr. Asik Ikbal
Government of West Bengal

*CORRESPONDENCE
Sagar Vitthal Shinde
shindesagy2@gmail.com

RECEIVED 29 May 2023
ACCEPTED 15 June 2023
PUBLISHED 27 July 2023

CITATION
Shinde and Sukhdhane, (2023) Minireview on Single Cell Protein Usage in Fisheries and Aquaculture. Chronicle of Aquatic Science 1(2): 8-15

Minireview on Single Cell Protein Usage in Fisheries and Aquaculture

Sagar Vitthal Shinde[1] and Kapil Sukhdhane[1]

[1]Division of Aquaculture, ICAR-CIFE, Panch Marg, Off Yari Road, Versova, Andheri (W), Mumbai, 400061

Single-cell protein (SCP) is a protein produced from the mass culture of microorganisms, such as bacteria, algae, and yeast. SCP has been proposed as a sustainable and environmentally friendly alternative to fishmeal, which is a major component of aquafeeds. There are several advantages to using SCP in fisheries and aquaculture. SCP can be produced from a variety of renewable resources, including waste streams from other industries, such as agriculture and food processing. This helps to reduce environmental impact by reducing the amount of waste that is produced and by diverting it from landfills. It is a complete protein, meaning that it contains all the essential amino acids that fish need to grow and thrive. This contrasts with some plant-based proteins, which are incomplete and must be supplemented with other amino acids. SCP is relatively inexpensive to produce. This is due to the fact that microorganisms can be grown in large, closed systems, which allows for efficient use of resources and control of environmental conditions. Despite these advantages, there are some challenges to using SCP in aquaculture. One challenge is that SCP must be produced in large quantities to meet the demand of the aquaculture industry. This can be a challenge, as SCP production facilities are expensive to build and operate. Another challenge is that SCP must be carefully processed to ensure that it is safe for fish to eat. This is because microorganisms can produce toxins that can be harmful to fish. Despite these challenges, SCP has the potential to be a breakthrough in the aquaculture industry. By providing a sustainable, affordable, and complete protein source, SCP can help to reduce the environmental impact of aquaculture and improve the health and welfare of farmed fish.

Keywords

Single-cell protein, Nutritional Enhancement, Disease Management, Waste Recycling

Introduction

The issue of providing adequate food supplies is increased by the world's fast-growing population. Protein supply, in particular, is a challenge since necessary amino acids cannot be substituted. Protein deficiency is becoming a big issue for humanity around the globe (Suman *et al.*, 2015). In fact, aquaculture has developed at a higher rate than any other animal protein sector during the last two decades, with a compound annual growth rate of 7% compared to 4% for poultry (Ritchie and Roser, 2019). Aquaculture diets have a larger crude protein level, ranging from 35-60 wt.%, than terrestrial cattle diets, which have a crude protein value of 12-26 wt% (Jones *et al.*, 2020)

As a result, in 1996, novel sources of protein biomass, namely bacteria, yeast, fungi, and algae, were employed to make Single Cell Protein (SCP). Carol L. Wilson invented the term SCP in 1966 (Suman et al., 2015). Single-cell proteins are produced using a range of microbes and substrates. Because of its exceptional nutritional quality, yeast is ideal for the generation of single cell proteins. Cereals that have been supplemented with single cell proteins, particularly yeast, are as good as animal proteins (Huang and Kinsella, 1986). Single Cell Protein refers to a protein derived from a microbiological source. SCP is expected to play a key role in its long-term success.

Single Cell Protein organisms

Microalgae, yeast and other fungi, and bacteria can all be used to make SCP products. All are now being researched and developed, and each has its own set of benefits and challenges.

Microalgae

Microalgae can be a SCP source with a reasonably high crude protein content, as (Tibbetts, 2018) recently evaluated. However, potential production of omega-3 fatty acids (i.e., Eicosapentaenoic acid and Docosahexaenoic acid) (Tocher *et al.*, 2019) and carotenoids, namely astaxanthin — an antioxidant, immunostimulant (Shah *et al.*, 2018), and pink pigment for salmon and shrimp (Hu *et al.*, 2018) by the strain Aurantiochytrium species appears to be more impactful.

Yeast and other fungi

Yeasts and fungi have long been used in animal feed, especially for terrestrial livestock and direct human consumption. *Saccharomyces cerevisiae*, different *Aspergillus* species, and *Fusarium venenatum* are the most well-known species, but *Candidautilis* and *Kluyveromyces marxianus* are getting popular as protein replacement strains (Overland *et al.*, 2013). However, in most cases, the purpose is to provide additional benefits, such as *Rhodotorula mucilaginosa* (Chen *et al.*, 2019) biomass, which has immunomodulation and antioxidant properties, and *Yarrowia lipolytica*, which produces eicosapentaenoic acid (EPA) and was previously marketed as Verlasso salmon (Tocher *et al.*, 2019) by DuPont and AquaChile.

Bacteria

Bacterial SCP strains may produce high crude protein content (>80 wt%) and Essential Amino Acids values, as well as vitamins, phospholipids, and other valuable compounds, from a variety of feedstock (Suman *et al.*, 2015). The variety of feedstocks has stimulated more research into bacteria that use methane, methanol, syngas, CO_2 and H_2, as well as second generation sugars.

Protists

Labyrinthulomycetes are heterotrophic marine protists that are divided into three groups: Thraustochytrids, Aplanochytrids, and Labyrinthulids (Leyland *et al.*, 2017). Because of their potentiality to generate omega-3 fatty acids, Thraustochytrids like *Schizochytrium limacinum* (*Aurantiochytrium limacinum*) are of particular interest (Ganuza *et al.*, 2019).

Table 1: Summary of SCP sources with current examples

SCP sources	Protein content range	Special characteristics	Example of specific organisms	Challenges	Current commercial activities
Microalgae	60–70% (Ritala *et al.*, 2017)	Phototrophic growth. Production of omega-3 fatty acids	*Chlorella vulgaris* *Desmodesmus sp.*	Economical scale-up Cell disruption to release nutrients	Cellana Pond Technologies BioProcess Algae
Yeasts	30-5-% (Ritala *et al.*, 2017)	Use of a variety of feedstock Production of vitamins and micronutrients	*Saccharomyces cerevisiae* *Candida utilis*	Improve protein and EAA content	ADM Alltech Flint Hills Resources ICC Brazil Pacific Ethanol
Bacteria	50-80% (Ritala *et al.*, 2017)	High protein content Growth on C1 substrates	*Methylococcus capsulatus* *Cupravidus nectar*	Palatability issues	Calysta Kiverdi KnipBio NovoNutrient White Dog Labs
Protists	10-20% (Moran *et al.*, 2017)	Production of omega-3 fatty acids	*Schizochytrium limacinum*	Improve protein content	Veramaris

Source: Jones *et al.*, 2020

Nutritional Value of SCP

Almost all essential amino acids are found in single-cell protein from bacteria and fungi, which may not be found in plant derivatives. Amino-nitrogen accounts for 70-80% of total nitrogen in microbial cells (Allison *et al.*, 1969). Algae are abundant in lipids and numerous vitamins such as A, B, C, D, and E. Antioxidant carotenoid pigments are found in *Bacillus* species. β-carotene, tocopherols, and B vitamins are all found in algae. B vitamins are also found in yeast; however filamentous fungi have a low vitamin concentration (Bharti *et al.*, 2014).

Table 2: Average Composition of the Main Group of Microorganisms (% dry weight)

Nutrients	Fungi	Algae	Yeast	Bacteria
Protein	30-45	40-60	45-55	50-65
Fat	2-8	7-20	2-6	1.5-3
Ash	9-14	8-10	5-9.5	3-7
Nucleic acid	7-10	3-8	6-12	8-12

Source: Miller and Litsky (1976)

Production Processes

The purpose of SCP production is to maximize cellular development and co-product yields in cost-effective ways, and the feedstock has a significant, if not the most significant, impact on costs.The production of single-cell protein (SCP) is a complex process that involves the following steps:

Selection of the microorganism: The first step is to select the microorganism that will be used to produce SCP. The microorganism must be able to grow rapidly and produce a high yield of protein. It is also important to choose a microorganism that is safe to eat and does not produce toxins.

Preparation of the substrate: The next step is to prepare the substrate that the microorganism will grow on. The substrate can be a variety of materials, including agricultural waste, food processing waste, or even human sewage. The substrate must be sterilized to kill any harmful bacteria.

Fermentation: The fermentation process is where the microorganism is grown and produces SCP. The fermentation process is carried out in a bioreactor, which is a large vessel that is designed to provide optimal conditions for growth. The bioreactor is filled with the prepared substrate and the microorganism is added. The bioreactor is then sealed, and the temperature and pH are controlled. The fermentation process can take several days or weeks, depending on the microorganism and the substrate.

Harvesting: Once the fermentation process is complete, the SCP must be harvested. The SCP can be harvested by centrifugation or filtration. Centrifugation spins the bioreactor at high speed, which causes the cells to clump together and form a pellet. The pellet is then removed from the bioreactor and the liquid is discarded. Filtration uses a filter to remove the cells from the liquid. **Drying:** The SCP must then be dried to remove the moisture. The SCP can be dried using a variety of methods, including air drying, drum drying, or spray drying.

Processing: The dried SCP may then need to be processed to remove any impurities. The SCP can be ground into a powder or pelletized.

Table 3: SCP production processes

Cultivation Operation	Growth modality	Capital & operational considerations	Emerging commercial examples
Aerobic Bioreactor	Heterotrophs Mixotrophs	• High cell mass yield • High capital costs • High energy consumption • Sterile operation • Significant installed industrial capacity	• Methanol, glycerol or ethanol – KnipBio • Glucose – Veramis • Cellulose – Arbiom & Menon
Anaerobic Bioreactor	Heterotrophs Mixotrophs	• Low cell mass yield • Low capital costs • Low energy consumption • Requires metabolite production and valorization • Non-sterile operation • Most installed industrial capacity	• Glucose or glycerol – White Dog Labs • Yeast sepatiation – Fluid Quip Technologies & ICM
Gas Bioreactor	Methylotrophs Chemoautotrophs Mixotrophs	• Variable cell mass yield • High capital costs • High energy consumption • Could require metabolite production and valorization • Sterile & non-sterile operation • Limited installed industrial capacity	• Methane – Calysta, Unibio, & String Bio • CO_2, H_2 & O_2 – Kiverdi, NovoNu-trients & Solar Foods • CO_2 & H_2 – LanzaTech • Glucose & syngas – White Dog Labs • CO_2 & light – BioProcess Algae & Pond Technologies
Photosynthetic Bioreactor	Photoautotrophs Mixotrophs	• High cell mass yield • High capital costs • High energy consumption • Sterile operation • No known installed industrial capacity	• Brewing by-products – iCell Sustainable Nutrition • Open photosynthetic system – Cellana

Open Cultivation Systems	Photoautotrophs Heterotrophs Mixotrophs	• Variable cell mass yield • Low capital costs • Low energy consumption • Non-sterile operation • Limited installed industrial capacity	

Source: Jones *et al.,* 2020

Advantages of SCP production

Single Cell Proteins are becoming increasingly popular as a result of their ability to grow on a little area of land while also helping in waste recycling (Hojaosadati *et al.*, 2000).

1. To begin with, it is a potential industry because the raw ingredients are free, or can be purchased at a low cost, but the products to sell are quite expensive. Not only that. It contributes to the reduction of pollution and the promotion of recycling.
2. It is rich in protein and low in fat. SCP organisms grow quicker and produce huge quantities of SCP from a limited amount of land and time. Genetic engineering allows the scientist to change the amino acid components of SCP.

Disadvantages of Single Cell Protein

There are certain drawbacks to use microorganisms or microbial biomass as a dietary supplement or as a single cell protein.

1. Many different types of microbes' release substances that are hazardous to both humans and animals. As a result, it must be ensured that the microbial biomass produced does not contain any of these toxic elements.
2. When used as a dietary supplement, microbial biomass can cause indigestion and allergic reactions in humans.
3. Many kinds of microbial biomass have a high nucleic acid content, which can cause poor digestion, gastrointestinal problems, and skin reactions in humans.
4. Single cell protein production is an extremely expensive technique since it requires a high level of sterility control in the manufacturing unit or laboratory.
5. Single cell protein produced as animal feed on agricultural wastes will benefit developing nations' economies in the future.

Further research and development will ensure that microbial biomass is used in developing countries as a single cell protein or as a diet supplement.

Importance of Single Cell Protein in Aquaculture

SCP acts as an immunostimulant and probiotic that significantly improves the growth, health, disease resistance, and immune system of cultured organisms, in addition to serving as an alternative protein source for aquafeeds. One of the most effective ways to control disease recurrence in intensive aquaculture is to use probiotics (Ige, 2013). *Lactobacillus* (gram-positive bacteria) as a probiotic has proven a viable alternative to antibiotics in aquaculture disease management (Kolndadacha *et al.*, 2011). Single-cell proteins from bacteria and yeast contain a significant amount of nucleic acid in the form of RNA. Microorganisms' increased amounts of RNA allow rapid protein synthesis (Adedayo et al. 2011). Rapid protein synthesis and rapid multiplication times are important characteristics in single-cell organisms with high protein content. Aquafeeds with a high nucleotide content increase hepatic function and lipid metabolism in fish. Because these compounds can be used as nutrition sources by bacteria, single-cell protein synthesis recycles waste from agriculture and industry. SCP can also recycle feed-derived wastes and ammonia released by cultured organisms.

Fish size and Colour are essential aspects in the success of ornamental fish aquaculture. Both can be modified by using SCP produced from algae and bacteria, which have high levels of carotenoid pigments. Microbial carotenoids can be used as a feed addition to promote ornamental fish growth and Colour.

Conclusion

Single-cell protein is an important alternative protein source that reduces input costs by utilizing naturally occurring microorganisms in aquaculture systems or other waste substrates that act as nutrition sources for growing microorganisms. Single-cell protein has a high nutritional value, promoting the growth and survival of cultured organisms through improving immune response and disease resistance. Single-cell protein can be a source of β-carotene, which can be used to improve the colour of ornamental fish. The use of SCP promotes one of the best and most convenient methods for producing low-risk, high-health- benefit organic food. Thus, the use of SCP in aquaculture increases production while being economically and environmentally viable.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

Conflict of interest

The authors declare that the manuscript was formulated in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Adedayo, M.R., E.A. Ajiboye, J.K. Akintunde and A. Odaibo. (2011). Single cell proteins: as nutritional enhancer. Advances in Applied Science Research2(5):396-409.

Bharti, V., Pandey, P.K. and Koushlesh, S.K. (2014). Single Cell Proteins: a Novel Approach in Aquaculture Systems. World Aquaculture, 45(4);62-63

Chen, X.Q., Zhao, W., Xie, S.W., Xie, J.J., Zhang, Z.H., Tian, L.X., Liu, Y.J. and Niu, J. (2019). Effects of dietary hydrolyzed yeast (*Rhodotorula mucilaginosa*) on growth performance, immune response, antioxidant capacity and histomorphology of juvenile Nile tilapia (*Oreochromis niloticus*). Fish Shellfish Immunology, 90:30-39.

Ganuza, E., Yang, S., Amezquita, M., Giraldo-Silva, A. and Andersen, R.A. (2019), Genomics, biology and phylogeny *Aurantiochytrium acetophilum sp*. nov. (*Thraustrochytriaceae*), including first evidence of sexual reproduction. Protist, 170:209-232.

Hojaosadati, S.A., Rasoul, K., Abbas, J., Hamid, R.S. (2000). Resources conservation and recycling. Journal of Chemical Engineering, 27(1-2): 125 138

Hu, J., Nagarajan, D., Zhang, Q., Chang, J.S. and Lee, D.J. (2018). Heterotrophic cultivation of microalgae for pigment production: a review. Biotechnology Advances, 36:54-67.

Huang, Y. T. and J.E. Kinsella (1986). Functional properties of phosphorylated yeast protein: Solubility, water-holding capacity and viscosity. Journal of Agriculture Food Chemistry, 344;670-674

Ige, B.A. (2013). Probiotics use in intensive fish farming. African Journal of Microbiology Research 7(22):2701-2711.

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

Kolndadacha, O.D., Adikwu, I.A., Okaeme, A.N., Atiribom, R.Y., Mohammed, A. and Musa, Y.M. (2011). The role of probiotics in aquaculture in Nigeria. Continental Journal of Fisheries and Aquatic Science 5(1):8-15.

Leyland, B., Leu, S., Boussiba, S. (2017). Thraustochytrids algae. Fungal Biology, 121:835-840.

Miller, B.M. and Litsky, W. (1976). Single Cell Protein in Industrial Microbiology. McGrow-Hill Book Co., New York.

Moran, C.A., Morlacchini, M., Keegan, J.D., Fusconi, G. (2018). The effect of dietary supplementation with Aurantiochytrium limacinum on lactating dairy cows in terms of animal health, productivity and milk composition. Journal of Animal Physiology and Animal Nutrition, 102:576-590

Overland, M., Karlsson, A., Mydland, L.T., Romarheim, O.H. and Skrede, A. (2013). Evaluation of *Candidautilis*, *Kluyveromyces marxianus* and *Saccharomyces cerevisiae* yeasts as protein sources in diets for Atlantic salmon (*Salmo salar*). Aquaculture 402-403:1- 7.

Ritala, A., Hakkinen, S.T., Toivari, M., Wiebe, M.G. (2017). Single cell proteinstate-of-the-art, industrial landscape and patents 2001-2016. Front Microbiology, 8:2009

Ritchie, H., and Roser, M. (2019): Meat and Seafood Production and Consumption.

Shah, M.R., Lutzu, G.A., Alam, A., Sarker, P., Chowdhury, M.A.K., Parsaeimehr, A., Liang, Y. and Daroch, M. (2018). Microalgae in aquafeeds for a sustainable aquaculture industry. Journal of Applied Phycology 30: 197-213.

Suman, G., Nupur, M., Anuradha, S. and Pradeep, B. (2015). Single Cell Protein Production: A Review. International Journal of Current Microbiology and Applied Science, 4(9): 251-262

Tibbetts, S.M. (2018). The potential for' Next-Generation', microalgaebased feed ingredients for salmonid aquaculture in context of the blue revolution. In Microalgal Biotechnology. Edited by Jacob-Lopes E, Zepka LQ, Queiroz MI. IntechOpen; 151-175

Tocher, D.R., Betancor, M.B., Sprague, M., Olsen, R.E. and Napier, J.A. (2019). Omega-3 long-chain polyunsaturated fatty acids, EPA and DHA: bridging the gap between supply and demand. Nutrients 4;11(1):89

Watanabe, K., Arafiles, K.H.V., Higashi, R., Okamura, Y., Tajima T, Matsumura Y, Nakashimada Y, Matsuyama K, Aki T (2018). Isolation of high carotenoid-producing *Aurantiochytrium sp.* mutants and improvement of astaxanthin productivity using metabolic information. Journal of Oleo Science, 67:571-578.