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Single Cell Protein: Microbial Protein for Sustainable Aquaculture Feed and Nutrition

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ABSTRACT

SCP, or Single Cell Protein, refers to microbial proteins derived from microorganisms like algae, bacteria, fungi, or yeast. It provides a sustainable and cost-effective protein source for various applications, including animal feed, human nutrition, and industrial processes, while reducing reliance on traditional protein sources and minimizing environmental impact. The review sheds light on the significance and versatility of Single Cell Protein (SCP) in various applications, particularly its role in addressing protein demands in aquaculture. As global demands for fish products escalate, the aquaculture industry faces the challenge of ensuring high-quality fish feed while minimizing costs. SCP, characterized by its excellent nutritional profile and cost-effectiveness, has emerged as a valuable protein source in aquaculture diets, offering an alternative to traditional fish meal. This shift away from fish meal, although partially achieved, still relies heavily on soy protein, emphasizing the need for novel protein sources that can ensure stability of supply and economic viability as the aquaculture industry continues to grow. Realizing this goal will require industry-wide commitment and substantial capital investment, potentially involving collaboration and co-investment by stakeholders across the value chain. Such efforts are critical to driving the sustainable production of aquaculture and reducing dependency on traditional protein sources, ultimately benefiting both the industry and the environment

KEYWORDS

Single cell protein, fish feed, protein source, agricultural waste.

Introduction:

Feed is a major cost in aquaculture production, and protein ingredients particularly dominate aquaculture feed cost. Diets of farmed fish are changing and fish meal must be increasingly replaced by other unconventional protein sources that will put less pressure on the environment. Thus, efficient feed is essential to manage production costs and improve the sustainability of aquaculture. In response to depleting fish stocks and increasing global aquaculture production, research and development around single-cell proteins (SCPs) is making headway as an alternate ingredient to replace fish meal in aqua and other livestock feeds. Single Cell Protein (SCP) is used to describe the dehydrated microbial cells that are produced from pure cultures of microorganisms such as algae, bacteria, yeasts, and filamentous fungi. These microorganisms are cultivated in controlled environments, often using waste materials or renewable resources as a substrate. The primary purpose of producing SCP is to obtain a high-protein biomass that can be used as a source of nutrition for both humans and animals. Approximately a century ago, Max Delbruek and his fellow researchers embarked on an exploration of the potential of surplus Brewer's yeast as a supplementary feed for animals. This marked the nascent stages of Single Cell Protein (SCP) production technology, a journey that traces its roots back to the utilization of yeast in bakery and beverage manufacturing as far back as 2500 BC.The significance of SCP gained even more prominence during the turbulent times of the First World War when Germany, facing protein source shortages, harnessed the growth of *Sachharomyces cerevisiae* as a means to replace imported protein sources. SCP production technology played a pivotal role in addressing this challenge. Likewise, during the Second World War, *Candida arborea* and *Candida utilis* were enlisted as yeast SCP sources, successfully replacing a substantial 60% of the country's protein intake (Adedayo et al., 2011).

In the 1960s, researchers at British Petroleum developed a technology called proteins-from-oil process for producing single cell protein by yeast fed by waxy paraffins, a product produced by oil refineries (Ageitos et al., 2011). Initial research work was done by Alfred Champagnatar and BP s Lavera, Oil Refinery in France; a small pilot plant there started operations in March in 1963, and the same construction of the second pilot plant, at Grange Mount oil refinery in Britain was authorised (Bamberg, 2000). The term "Single Cell Protein" (SCP) as we know it today was first coined by Carroll L. Wilson of MIT in 1966 as a more appealing alternative to "microbial protein." The interest in producing and using microbial biomass as a protein source surged, primarily because of its elevated protein content. Besides proteins, SCP also encompasses other essential nutrients like lipids and vitamins. The utilization of SCP in creating novel fish meal solutions presents a dual benefit: it reduces the handling of waste materials and offers a sustainable protein source for aquaculture. The commercial availability of SCP products took a significant step forward with the introduction of the first commercially available SCP, which was sold under the name 'PRUTIN.'An intriguing aspect of SCP production is that in most cases, microorganisms thrive as individual cells or filamentous entities, lending credence to the aptness of the term "Single Cell Protein."

Production of Single Cell Protein (SCP):

The production of Single Cell Protein (SCP) represents a pivotal endeavor in the realm of sustainable protein sources. SCP, derived from the deceased, dehydrated cells of microorganisms, or alternatively, may involve the purification of proteins isolated from microbial cell cultures (Queiroz et al., 2007). This resourceful protein source finds application in animal feed, including poultry, calves, pigs, and fish, and extends its utility to industries such as leather and paper production (Raziq et al., 2020). Crucially, SCPs are characterized by their impressive protein content, often ranging between 60% to 80% on a dry matter basis. Additionally, these proteins are rich in essential amino acids like methionine and lysine.

The production process of SCP is multifaceted, involving several key steps:

Substrate Selection and Pre-treatment: The journey begins with the careful selection of a natural and cost-effective substrate. Often, these substrates require physical or chemical pre-treatment to enhance their compatibility with microbial utilization.

Medium Supplementation: To promote optimal microbial growth, the fermentation medium is supplemented with essential nutrients, including carbon, nitrogen, phosphorus, and other vital elements.

Sterilization and Inoculation: Ensuring a sterile environment is crucial. The fermentation medium is sterilized, followed by the inoculation of pure-state microorganisms, setting the stage for either solid-state or submerged fermentation.

Process Optimization: The process parameters are meticulously fine-tuned to maximize microbial protein production.

Harvesting: The microbial biomass is harvested, setting the stage for storage and eventual application.

Notably, the sources for SCP production vary from conventional substrates like starch, fruits, molasses, and fruit waste to unconventional ones such as petroleum by-products, ethanol, natural gas, lignocellulosic biomass, and methanol. This diversity in substrates underscores the adaptability of SCP technology to various resource streams (Zepka et al., 2008).

Single Cell Protein (SCP) from Microorganisms:

The utilization of microorganisms in the production of Single Cell Protein (SCP) has garnered significant attention due to several advantageous characteristics inherent to these tiny yet versatile organisms. SCP, as a sustainable protein source, offers a range of benefits that are reshaping the landscape of protein production and addressing some of the challenges associated with traditional sources.

Rapid Multiplication and Short Generation Time: Microorganisms are renowned for their high reproductive rates and short generation times. This inherent ability allows for the rapid growth and propagation of microbial populations, leading to efficient and swift protein production (Khadse et al., 2018). Microorganisms can be genetically manipulated to tailor their amino acid composition to meet specific nutritional requirements and exhibit a remarkable capacity to utilize a wide spectrum of substrates as carbon and energy sources (Kelechi Ukaegbu-obi, 2016). This versatility in substrate utilization allows SCP production to be flexible and adaptable to various feedstocks, including waste materials and renewable resources. Unlike traditional agriculture, SCP production is not dependent on climatic or seasonal variations. This resilience to environmental fluctuations ensures a consistent and stable protein supply throughout the year, reducing the vulnerability of food and feed production to weather-related challenges (Adedayo et al., 2011). To harness the full potential of microorganisms for SCP production, certain key characteristics should be considered when selecting the microbial strains:

a) **Good Nutritional Profile**: Microorganisms chosen for SCP production should possess a robust nutritional profile. This includes high protein content, essential amino acids, and other important nutrients that make SCP a valuable protein source (Wu et al., 2014).

b) **Suitability for Food and Feed**: The selected microorganisms should be safe and suitable for consumption as both human food and animal feed. This ensures that SCP is a versatile protein source that can meet various dietary needs.

c) **Lack of Toxic Compounds**: Microbial strains used for SCP production should not contain toxic compounds or contaminants that could pose health risks to consumers. Ensuring the safety of SCP products is paramount.

d) **Low Production Costs**: SCP production should be cost-effective to make it a competitive protein source. Efficient cultivation processes and substrate utilization are essential to keep production costs low (Junaid et al., 2020).

The Microorganisms used are:

1. Bacteria:

Bacteria are preferred for SCP production due to their rapid growth rates compared to other microorganisms. Their ability to efficiently utilize a wide range of substrates makes them valuable in the context of SCP production. However, the substantial quantities of bacteria involved in SCP production necessitate stringent sterilization conditions to prevent contamination by pathogenic bacteria. Most bacterial SCP production processes operate within a pH range of 5 to 7 (Liu et al., 2014). Bacterial SCP is known for its high protein concentration, often reaching around 80%. However, it is worth noting that bacterial SCP contains a high proportion of nucleic acids, particularly RNA, which can be as high as 20%. This necessitates processing steps to reduce nucleic acid content before use in nutrition. While bacterial SCP boasts a favorable amino acid profile, it tends to be low in sulfur-containing amino acids. Additionally, it is important to consider the potential production of endotoxins by certain types of Gram-positive bacteria during SCP production.

2. Algae:

Algae, particularly species from genera such as Chlorella, Scenedesmus, and Spirulina, are prominent in SCP production. Algae predominantly rely on photosynthesis for growth, with light being a critical factor in commercial production. Open ponds exposed to sunlight are commonly used for algae biomass production, although challenges related to pollution and sterilization persist. Algae-based SCP can contain up to 60% protein and exhibits a favorable amino acid composition, albeit with lower sulfur-containing amino acids. Algae are rich in photosynthetic pigments, making them desirable for compound feed preparation but less suitable for direct human consumption (Nasseri et al., 2011). Studies have shown promising results when microalgae are incorporated into animal diets, particularly for animals requiring high protein intake (García-Garibay et al., 2014).

3. Yeasts:

Yeast production on a commercial scale has a history spanning over a century, with species like Saccharomyces, Candida, and Torulopsis being prominent choices (Gao et al., 2012). While yeast growth rates are not as rapid as certain bacteria, they still offer efficient protein production. Adjusting the pH to a range of 3.5 to 5.0 during yeast cultivation helps mitigate the risk of bacterial contamination. Yeast-based SCP typically contains 55-60% protein and about 15% nucleic acids on a dry weight basis (Klug et al., 2014). Therefore, post-processing steps are necessary to reduce nucleic acid content. Yeasts have a favorable amino acid profile, although they may lack sulfur-containing amino acids, which can be supplemented with methionine. Additionally, yeast-based SCP often contains B-group vitamins (Kieliszek et al., 2017).

4. Filamentous Fungi:

Filamentous fungi, while exhibiting lower growth rates compared to bacteria and yeasts, offer specific advantages in SCP production. Some micro-fungi can achieve growth rates that approach those of yeasts. Growing fungi at a pH of 5 reduces the risk of bacterial contamination and simplifies yeast cell separation. Filtration is often employed for cell separation in fungal SCP production. Filamentous fungi can contain a substantial amount of raw protein, up to 50-55%, although a significant proportion of this may be in the form of cell wall components (Ravinder et al., 2003). Nevertheless, fungal SCP is generally rich in amino acids (Al-Mudhafr, 2019). Care must be taken to prevent the production of toxins during the fungal SCP production process.

Choice of Substrates in Single-Cell Protein (SCP) Production:

The production of Single-Cell Protein (SCP) is a versatile process that can utilize a wide range of substrates, both conventional and nonconventional. These substrates play a crucial role in SCP production and can be broadly categorized into three groups: high-energy sources, various wastes, and renewable plant sources.

High-Energy Sources: High-energy sources are unconventional substrates that offer significant carbon and energy content for microorganisms to convert into SCP. These sources include:

Petroleum Wastes: SCP production from petroleum fractions is possible, especially those containing C12 to C22 hydrocarbons (Taran et al., 2014). Substances such as acetic acid, natural gas, gas oil, methane, methanol, and n-alkanes can serve as substrates. For example, British Petroleum used C12-C20 alkanes, a wax fraction of gas oil, with *Candida lipolytica* and *C. tropicalis* for SCP production. However, it's important to note that the use of petroleum wastes as a substrate carries the risk of generating toxic and carcinogenic by-products (Nasseri et al, 2011).

Various Wastes:

Various waste materials, including agricultural and industrial by-products, can serve as substrates for SCP production. These wastes are not only cost-effective but also contribute to environmental sustainability by recycling and repurposing materials (Jalasutram et al., 2013). Some examples include:

Agricultural Wastes: Agricultural waste materials, such as fruit and vegetable waste, including seeds, peels, and pulps, are valuable substrates for SCP production. In countries like India, where agriculture is a prominent industry, the utilization of agricultural and agro-based industrial wastes can help mitigate environmental hazards associated with improper disposal (Thiviya et al., 2022).

Dairy Wastes: Whey, a by-product of the dairy industry, contains approximately 50% of the nutrients found in milk, including lactose (about 70%), protein, minerals, and vitamins. Whey can be considered a potential substrate for SCP production, particularly using microorganisms capable of metabolizing lactose (Putri et al., 2018). This approach not only reduces environmental pollution by repurposing dairy waste but also contributes to addressing issues of hunger and malnutrition. Yeasts like Kluveromyces lactis, K. marxianus, and Saccharomyces cerevisiae are capable of fermenting the lactose in whey for SCP production (Babu et al., 2014).

Plant Sources which are Renewable in Nature:

Renewable plant sources offer sustainability in SCP production. These sources can be continually replenished, reducing the strain on finite resources. Renewable plant sources often include materials like lignocellulosic biomass and other plant-derived substrates.

ADVANTAGES OF SCP

- **SCP as an Alternative to Fishmeal in Aquaculture:**

The application of Single Cell Protein (SCP) in fish meal formulation has emerged as a pivotal strategy to meet the escalating protein demands of aquaculture, driven by the rising global demand for fish products (Ayadi et al., 2012). As the aquaculture industry continues to expand to satisfy this demand, the need for high-quality fish feed has grown in parallel. Protein constitutes the most expensive component of commercially available fish feed (Hua, et al., 2019). In response to the increasing cost of fish meal, aquaculture has sought innovative solutions to optimize feed formulations while ensuring optimal nutrition for aquatic species. SCP, characterized by its excellent nutritional profile, has been integrated into aquaculture diets as a partial replacement for traditional fish meal, providing a cost-effective and high-quality alternative protein source (Bogdahn, 2015). This approach has alleviated the challenges posed by the rising prices of fish meal. The advantages of SCP in aquaculture include its relatively low production cost, ready availability of substrates, and ease of production, all contributing to the reduction of fish feed expenses (Karimi, et al., 2018). Use of organic SCP derived from yeast species such as *Yerrowia lipolytica* has been successfully incorporated into the diets of various aquatic species, including *Lepidocephalus thermalis* (Patil and Jadhav, 2014). Moreover, bacterial SCP, exemplified by *Methylobacterium extorquens*, has been utilized in the formulation of feeds for species such as white shrimp (*Litopenaeus vannamei),* small mouth grunt (*Haemulonchrys argyreum*), and Atlantic salmon (*Salmo salar*) (Tlusty et al., 2016). These developments represent significant strides in aquaculture, reflecting a shift towards sustainable and cost-effective protein sources, ultimately benefiting both the industry and the environment (Hadi et al., 2021). Some main advantages of SCP as feed are:

Superior Protein Profile: SCP from microbial and algal cells is an ideal substitute for fishmeal in aquaculture. It offers higher protein levels with superior amino acid profiles and nucleotide content (Suman et al., 2015).

Reduced Antigens: Unlike plant proteins like soybean meal, SCP does not contain antigens that interfere with amino acid absorption and raise the Feed Conversion Ratio (FCR).

Use of Yeasts and Fungi: Yeasts and fungi, including species like *Saccharomyces cerevisiae, Aspergillus, Fusarium venenatum, Candida utilis,* and *Kluyveromyces marxianus* are employed as potential protein replacements in animal feed, providing antioxidants and immunomodulation effects (Jones et al., 2020).

- **SCP in Nutrition and Animal Feed:**

High Protein Content: SCP contains more than 30% protein in its biomass, making it a potent protein source for both humans and animals. This protein content provides essential nutrients for growth and development (Sharif *et al.*, 2021).

Balanced Amino Acid Profile: SCP offers a balanced array of essential amino acids, making it a valuable source of high-quality protein. To access nutritional value of single cell protein, many factors must be considered which include nutrient composition, amino acid profile, vitamin and NA content as well as allergies and gastrointestinal effects (Dunuweera *et al.*, 2021).

Efficient and Sustainable Production: Microbial protein can be cultivated with high growth rates and the ability to utilize unique substrates like CO2 or methane. This results in processes that are more efficient and sustainable than traditional agriculture.

Independence from Seasonal Factors: SCP production is not affected by seasonal variations, ensuring a consistent protein supply throughout the year.

Environmental Benefits: SCP production efficiently utilizes waste or raw materials, contributing to waste reduction and minimizing environmental pollution (Bertasini et al., 2022).

SCP finds extensive use in animal diets, benefiting various livestock and aquaculture species.

Fattening Calves, Pigs and Broilers: SCP is incorporated into the diets of animals like calves, pigs, and broilers to promote growth and development.

Hens Feed: SCP supplements are used in laying hen feed to ensure optimal egg production.

Fish breeding and Feeding: SCP plays a crucial role in fish breeding and feeding, contributing to the growth and health of fish populations (Sharif et al., 2021).

Pet Food: SCP is also used in pet food formulations, providing essential nutrients for pets' well-being.

- **SCP in Food Production and Industrial Applications:**

Foodstuffs: SCP is utilized in various food products as an emulsifying agent, carrier of vitamins and scents, and as a nutritional supplement. It is incorporated into soups, baked items, ready-made meals, and food recipes to enhance their nutritional value (Ritala et al, 2017).

Leather and Paper Processing: SCP has applications in the leather and paper processing industries, where it contributes to the production process.

Foam Stabilizing Agent Industry: SCP is used as a foam stabilizing agent in industrial applications, demonstrating its versatility beyond nutrition.

- **Medicinal Uses and Spirulina:**

Medicinal Applications: Certain microorganisms like Spirulina have demonstrated medicinal properties, including enhanced antiviral and anticancer activity. Additionally, they can strengthen the immune system (Alamgir, 2018).

Conclusion

Reducing the aquaculture industry's reliance on marine ingredients and soy protein for fish feeds is a critical step toward sustainability as the sector continues to expand to meet global seafood demands. While progress has been made in decreasing the use of marine-based ingredients and trimmings, soy protein remains a significant component in aquaculture feeds. However, to ensure the stability of supply and economic viability of the aquaculture industry, it is imperative to explore novel raw materials that are rich in protein. The challenge lies in the scalability and market viability of these novel protein sources. While there is a desire to introduce such raw materials into aquaculture feeds, achieving this goal is not straightforward. It requires a commitment from the entire industry and substantial capital investment. Collaborative efforts across the entire value chain are essential to drive the sustainable production of aquaculture and make the large-scale production of single-cell protein a reality. These collaborative initiatives are also crucial for addressing the sustainability challenges facing the aquaculture industry and ensuring a stable, cost-effective, and environmentally responsible supply of protein for fish feeds. Every participant in the value chain plays a vital role in making this transition happen and enabling the widespread adoption of single-cell protein production at scale.

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