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LABORATORY SYNTHESIZED PROTEINS: SCP

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The world is now undergoing a paradigm shift from food security to nutritional security. People these days have been more conscious about the nutritive value of the food they intake. Also, in parts of world, where undernourishment prevails among women and children, the scarcity of protein-rich food has forced mankind to search for alternative protein sources that can replace conventional, but expensive sources. Under such circumstances, innovations like Single Cell Proteins emerge as saviour to serve the purpose. It can be used as diet supplement to meet protein requirement by replacing costly conventional sources like soymeal and fishmeal. SCPs are microbial biomass obtained from growing them on various substrates post fermentation. This bioconversion of agricultural and industrial wastes to protein-rich food and fodder has an additional benefit of making the final product cheaper and expanding the utility of final product. After rigorous examinations, these proteins can be directly used as food and feed supplements for humans and animals, respectively. There is need to standardize and streamline the process of SCP production and improve the quality and quantity of biomass production using new and improved microorganisms. If used properly, it has the potential to address undernutrition challenges in a manner that is both cost- and environment- friendly, heralding a transformative era in nutritional science.

Background

The burgeoning global population is facing a pressing challenge: protein and micronutrient deficiency. As populations expand, dietary needs escalate, worsening the dependency on traditional protein sources. Concurrently, there's a distressing trend of diminishing lifespans and compromised quality of life due to inadequate nutrition. To deal with this crisis, there is need to explore novel, cost-effective and sustainable protein sources. In this context, Single Cell Protein (SCP) emerges as a beacon of hope. SCP production, often confined to small rooms or controlled environments, offers a remarkable solution. Within these compact spaces, substantial quantities of high-quality protein can be cultivated from various substrates, ensuring a reliable supply. Moreover, the affordability of SCP broadens its accessibility for plethora of end uses. This accessibility extends beyond human consumption, including animal nutrition as well. Cheaper protein inputs enhance livestock diets, fostering healthier animals and amplified returns for the farmers.

Introduction to Single Cell Protein (SCP)

The term 'single cell protein' was coined in 1968 at a meeting held at the Massachusetts Institute of Technology (MIT) to replace the less aesthetic 'microbial protein' and 'petroprotein' which were the terms originally used for the purpose.

SCP or the Single Cell Protein refers to the protein obtained from dried microbial mass grown on a variety of substrates and allowed to ferment under controlled conditions. Micro-organisms utilize a variety of substrates like agricultural waste, food residues, industrial effluents, sewage waste, lignocellulosic waste or even natural as like methane. Concomitantly, they are responsible for biodegradation of large amount of organic waste. While undergoing fermentation, complex organic molecules are broken down into simple acids and alcohols (Tropea *et a*l., 2022). The fermented products are put to downstream processing like washing, cell disruption, protein extraction and purification to obtain the final product which is used as protein supplement for human or animal consumption. It has shown a great advantage in current scenario because of its independence from soil-climatic conditions and land availability (Hülsen *et al*., 2018).

Understanding Single Cell Protein Production

A. Microorganisms as Producers: Algae, fungi and bacteria are the chief sources of microbial protein that can be utilized as SCP (Table 1). Since ancient times, people have been harvesting *Spirulina* from the waters and using it as food after drying. A variety of algae form an important food source for fish, aquatic amphibians, mammals and other animals. Many fungal species are also used as protein-rich food. Most popular among them are the yeast species *Candida*, *Hansenula*, *Pitchia*, *Torulopsis* and *Saccharomyces.* Among bacteria, *Cellulomonas* and Alcaligens are the most frequently used species as an SCP source.

Table 1: List of microorganisms used for SCP production

Fungi	Bacteria	Algae
Saccharomyces cereviceae	*Methylococcaceae*	*Alaria*
Aspergillus niger	*Brevibacterium spp.*	*Laminaria*
Chaetomium cellulolyticum	*Cellulomonas spp.*	*Nostoc*
Chrysonilia sitophilia	*Methanomonas methanica*	*Rhodymenia*
Fusarium graminearum	*Methylophilus methanotrophus*	*Ulva*
Penicillium roqueforti	*Pseudomonas fluorescens*	*Spirogyra*
Penicillium camemberti	*Rhodopseudomonas gelatinosus*	*Chlorella*
Trichoderma album	*Streptomyces spp.*	*Oedogonium*
Scytalidium acidophilum		*Sargassum*

B. Substrates: A variety of substrates have been utilized to cultivate bacteria, fungi and algae to yield SCP. The main requirements for growth of microbes are carbon dioxide and sunlight which can be sourced from food and agricultural waste like sugarcane bagasse, wheat straw, wheat bran, rice bran, groundnut shell, paper and wood industry refutes, food wastes, industrial effluents etc. The use of such materials for SCP production serves the dual purpose of protein production and waste management.

C. Production process:Production process begins with selection of suitable microbial strains and subsequently their optimization *via* selection, mutation and other genomic tools. Then the technical conditions required for their growth and multiplication are standardized and fermentation is allowed under controlled conditions in big tanks or incubators. Downstream processes are done to purify and enrich the final product. (Figure 1) After that, rigorous checking is done for safety and potential risks that can be due to presence of toxins, heavy metals or carcinogens.

D. Nutritional Content: The nutritive value and utility of Single Cell Protein (SCP) are dependent upon the substrate and subsequent processing methods. Algae exhibit richness in protein, fats, and a spectrum of vitamins including A, B, C, D, and E. Specifically, planktonic algae serve as the primary source of vitamins A and D. Algae has a composition of 40–60% protein, 7% mineral salts, chlorophyll, bile pigments, fiber and a notably low nucleic acid content ranging between 4–6% (Anupama and Ravindra, 2000). Conversely, fungi predominantly provide the B-complex group of vitamins, with yeast containing an array of essential nutrients such as thiamine, riboflavin, biotin, niacin, pantothenic acid, pyridoxine, choline, streptogenin, glutathione, folic acid and p-amino benzoic acid. Bacterial SCP is enriched with methionine, with concentrations ranging between 2.2–3.0%, surpassing levels found in algae (1.4–2.6%) and fungi (2.5–1.8%). But it contains high levels of protein and specific essential amino acids. Bacterial SCP also exhibits a notable concentration of nucleic acids, particularly RNA, accounting for approximately 15–16% of its dry weight.

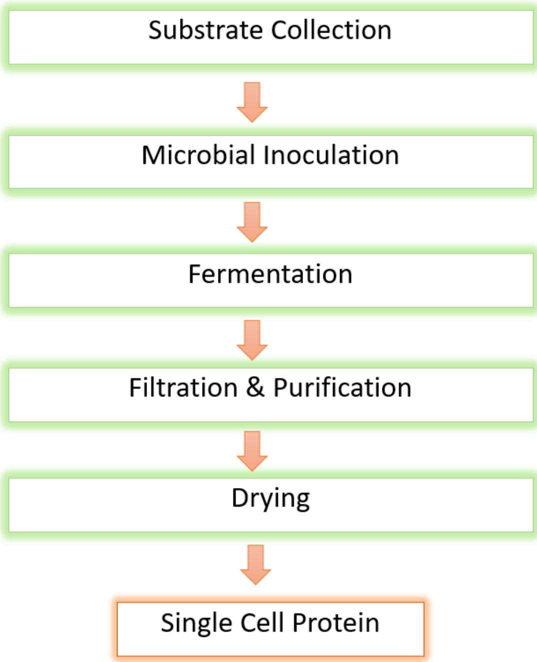

Fig 1: SCP Production Process

Applications

A. Human Nutrition: SCP can be utilized in human nutrition as a protein supplement or food ingredient. It can be incorporated into various food products such as bread, pasta, snacks and beverages to enhance their nutritional value. SCP-based foods offer a sustainable and cost-effective source of protein, particularly in regions facing protein deficiency or food insecurity.

B. Livestock Feed: Livestock farming is one of the primary consumers of protein-rich feeds, with conventional sources like soybean meal, fishmeal, meat and bone meal dominating the market. SCP offers several advantages over traditional protein sources in livestock feed. Firstly, it can be produced using a variety of low-cost substrates, including agricultural residues, food waste and industrial by-products, making it a sustainable and cost-effective alternative. Secondly, SCP production can be scaled up rapidly, providing a consistent and reliable source of protein for livestock farmers.

C. **Aquaculture:** Aquaculture is another sector that stands to benefit from the adoption of Single Cell Protein (SCP) as a feed ingredient. Fishmeal has traditionally been a key ingredient in aquafeeds. Its finite supply and rising costs have led to the acceptance of SCP as it can offer similar nutritional benefits to fishmeal, providing a source of high-quality protein and essential nutrients for farmed fish and shrimp.

D. **Soil Health and Plant Nutrition:** Apart from its applications in animal nutrition, Single Cell Protein (SCP) also holds promise for improving soil health and plant nutrition in agriculture. SCP biomass can be processed into biofertilizers, that enhance soil fertility and plant growth by improving nutrient cycling, soil structure and microbial activity, leading to higher crop yields, better nutrient uptake and reduced dependence on chemical fertilizers. In addition to this, they can also act as plant growth promoters by stimulating root development, increasing nutrient availability and enhancing resistance to biotic and abiotic stresses.

E. **Pharmaceuticals and Biotechnology:** SCP-derived proteins and enzymes have applications in pharmaceuticals, biotechnology, and industrial processes. They can be used for the production of therapeutic proteins, enzymes, bioactive compounds, and specialty chemicals, offering a sustainable and scalable alternative to traditional manufacturing methods.

Limitations

Every novel innovation has its proponents as well as critics. While the proponents understand the potential SCP holds to meet the protein demands, the critics focus on anti-nutritional factors, psychological and social factors to use microbes as source of food. It is important for a researcher to look at the both sides of coin and elaborate the pros and cons vividly.

Among the various microbes, algae are the most acceptable one due to its age-old prevalence to be used as food material, mainly for aquatic animals. Although algae are very good nutrition sources, presence of cellulose rich cell wall limits its use. Humans lack the cellulase enzyme and therefore, the wall must be digested prior to eating. This digestion step is not required if the SCP is used as feed for cattle as they have cellulose-degrading symbiotic bacteria and protozoa in their rumen.

Intake of nucleic acid beyond an acceptable concentration content leads to the production of uric acid which accumulates in the body due to a lack of the uricase enzyme and may lead to kidney stone formation and gout in humans. Bacterial SCP products have nucleic acids as high as 16% of dry weight (Nasseri *et al*., 2011). Hence, there is need to reduce it to acceptable limits which can be done by activation of endogenous RNAase, alkaline hydrolysis of nucleic acids, chemical extraction and removal of nucleic acids.

Some bacteria and fungi produce toxins during growth that are actually their secondary metabolites. Prominent fungal toxins include aflatoxins from *Aspergillus flavus*, citrinin *from Penicillium citrinum*, trichothecenes and zearalanone from *Fusarium* species and ergotamine from *Claviceps* species. Bacteria produce either endo or exotoxins. Exotoxins are secreted by gram-positive bacteria into the surrounding medium. Some exotoxins are: enterotoxin, erythrogenic toxin, alpha-toxin and neurotoxin. Endotoxins are an integral part of the cell walls of gram-negative bacteria and are liberated upon lysis. The toxicity of the SCP product must be assessed before marketing it. Even Minute quantities of toxins can produce allergies, diseases, rashes on skin, neurotoxicity and other disorders. Exotoxins can be easily removed as they are sensitive to higher temperatures. However, formation of endotoxins can be reduced by genetic engineering of the strains by suppressing or inactivating the toxin producing genes cascade.

The SCP may even carry carcinogenic factors as contaminants if they are present in significant concentration in the substrates used. Algae also has the ability to accumulate heavy metals which should be critically examined. Hence, proper decontamination and purification of the final product is required before it is used as a food source either for humans or animals. For this, rigorous sanitation and quality control procedures must be maintained throughout the process.

Conclusion

Due to the high production cost, lack of awareness among masses and poor marketing strategies, SCP still lags to become part of a human diet. Therefore, the future of SCP will heavily depend on reducing the production costs, improvement of producer organisms and educating young minds about its core value.

Production costs can be minimized by standardizing the fermentation and downstream processing, use of in-house substrate as culture media, use of producer strains with high conversion ratios, improving the quality of end product by testing and purification. Improvement in protein recovery can also be achieved by suppression or elimination of protease activity in the microbial cells. Mutants with a modified protease gene sequence can be isolated and used for this purpose. Recombinant DNA technology can be used to isolate mutant genes that can produce high amounts of specific amino acids like glutamate, tryptophan and phenylalanine along with high protein yields. Such genes were combined by recombination techniques and incorporated into an organism with a wide substrate range. Novel techniques like Solid state fermentation (SSF) which involves the growth of microbes on a chiefly insoluble substrate, give higher biomass and protein yield. Also, there is need to implicate regulatory measures that can uniformly control the quality of SCP, benefitting the consumers and producers as well.

In conclusion, Single Cell Protein (SCP) holds immense potential to revolutionize various sectors, including agriculture, aquaculture, human nutrition, and environmental remediation, provided that adequate research, supportive policies, and widespread understanding of its necessity and benefits are in place.

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